The Metabolism and Energy Transformations of Healthy Man Duriug Rest

BY

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PREFACE.

The experiments reported herewith were made with the respiration calorimeter in the chemical laboratory of Wesleyan University, Middletown, Connecticut, at intermittent periods between March 23, 1903, and May 23, 1906, by the aid of grants from the Carnegie Institution of Washington. In the conduct of these experiments we were assisted by Messrs. W. H. Leslie, E. M. Swett, and J. A. Riche, members of the staff engaged in research in the nutrition of man. The computations and presentation of the results were of necessity deferred until the Nutrition Laboratory was built and at least in part equipped. During the past two years Mr. W. H. Leslie has been engaged in the calculations and tabulations, and we have benefited by his helpful editorial criticism.

Miss A. N. Darling has personally supervised the revision of the entire manuscript and has had charge of the stenographic work, ably assisted by her two associates, Miss K. E. Murphy and Miss I. M. Bates.

The accurate presentation of these results is in large part due to the painstaking care of the computing staff, consisting of the Misses F. E. Kallen, Alice Johnson, and P. H. Colbeth.

It is a pleasure to acknowledge our thanks to these and other co-workers who made the prosecution of this inquiry possible. Our thanks are also due to the large number of individuals who volunteered as subjects in the various experiments. Among these, special mention should be made of Dr. J. H. Kellogg and Mr. Horace Fletcher.

Nutrition Laboratory, Carnegie Institution of Washington,
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The Metabolism and Energy Transformations of Healthy Man During Rest.

BY

FRANCIS G. BENEDICT and THORNE M. CARPENTER.

PART 1. INTRODUCTION.

The greatest strides in medicine during the past decade have unquestionably been made in that particular branch of science designated as preventive medicine. Efforts on the part of hygienists, aided by chemists and bacteriologists, to have mankind live normal, clean lives, to breathe pure air, drink pure water, and partake of clean and suitable foods, have been productive of most astonishing results. These efforts have resulted in a marked influence on the inroads of disease and have, perhaps, more than any other one factor, been instrumental in emphasizing just what is "normal" in life. Previously little attention was paid to ventilation, water-supplies, and food, other than spasmodic efforts to better existing conditions when some epidemic necessitated such reform; to-day the education of the people has so steadily progressed that a much more general interest is taken in hygiene and the normal in life, and it is no longer customary to wait until some dire calamity makes imperative an examination of existing conditions and their influence on those factors which play so important a rôle in the normal, healthy life of man.

Accompanying the general interest in affairs of health is found a noticeable advance in our knowledge of physiological processes, particularly those processes pertaining to the use and digestion of food. Our knowledge of the chemistry and physiology of digestion was, in earlier days, based in large part upon the observations of William Beaumont[1] on Alexis St. Martin. These were surprisingly accurate, considering the knowledge of physiology at that time. Now, thanks to the researches of Pawlow[2] and Cannon,[3] these subjects have been made much clearer. The chemistry of food and the general processes of the nutrition of man have attracted the attention of many European scientists for a number of years, and in our own country wonderful advances in the study of nutrition have been made by Atwater.[4]

All of these researches contribute greatly to our knowledge of physiology and thereby, indirectly at least, supplement the investigations on preventive

[1] William Beaumont, Experiments and observations on the gastric juice and the physiology of digestion, Plattsburgh, 1833.

[2] Pawlow, Ergebnisse der Physiologie, 1902, Biochemie, p. 277; Arbeit der Verdauungsdrüsen, Wiesbaden, 1898.

[3] Cannon, W. B., Numerous papers in the American Journal of Physiology, 1898–1909.

[4] Atwater, Numerous papers, particularly in the bulletins of the United States Department of Agriculture, 1895–1903.

medicine, but there is a strong feeling that the nutritive processes during disease have been too little studied, in spite of the admirable researches of von Noorden, Magnus-Levy, Naunyn, and others. A decided advance has indeed been made in the general knowledge of physiology and excellent results have been obtained in the field of pathological research, and yet the data regarding pathological metabolism are too often of little or no value owing to the fact that there is still a lack of adequate comparative data during health.

LIMITATIONS OF NORMAL DATA AND ACCEPTED STANDARDS.

An intelligent study of pathological metabolism can only be made after a thorough investigation of normal metabolism. In dealing with sickness, there is a constant desire on the part of the physician for knowledge regarding the patient's normal physiological processes. If he knows exactly what is the course of events in a normal life, he can much more satisfactorily interpret the abnormal course that life may take during disease. This is true not only for the complex chemical and energy transformations, but for the simpler indices of life processes, such as the rate of the heart-beat, respiration-rate, and body-temperature.

The accumulations of years of observation on these fundamental indices by innumerable physiologists, medical examiners, and military physicians have given us certain average values that are called normal, and yet a critical examination of the methods used by the various writers, and of the condition, both physical and psychical, of the subject at the time of the examination, gives us an undeniable right to question the values thus obtained as normal values.

Normal body-temperature.—With body-temperature, the averaging of a great number of measurements has resulted in the common belief that 98.6° F. is the normal body-temperature. This assumption may lead at times to considerable difficulty by virtue of the fact that many people otherwise perfectly healthy may have a subnormal or hypernormal temperature. Furthermore, we now know that the normal body-temperature varies perceptibly with muscular work and even with the time of day. Similarly, the respiration-rate, pulse-rate, and blood-pressure all range within certain limits, the average of which is called normal.

Change in body-weight as index of physical condition.—In addition to the pulse, temperature, and respiration, the physician is constantly inquiring into the variations in body-weight. Our knowledge of the changes in body-weight and the factors upon which they depend are notoriously unsatisfactory and uncertain. The income of the body is made up of a large number of elements—water, protein, fats, carbohydrates, ash, and oxygen from the air. The outgo consists of water of urine and feces, water-vapor, carbon dioxide, and the unoxidized material in feces and urine. In attempting to strike a balance between income and outgo one may find very wide discrepancies between the apparent

and actual conditions. This is particularly the case when only the gross income, *i. e.,* the weight of food and drink is known, and the changes in body-weight are used as an index of gain or loss of body-material. The large proportion of water in the body may permit of a considerable draft upon it or an addition thereto may be made, and while the body may have gained 1 kilogram in weight this gain is not necessarily due to increase of organic material—either protein, fat, or carbohydrate—but it may be wholly water, or part water and part organic material, or it may even be an actual loss in organic material, compensated by an extra gain in water.

The character of the diet influences to a great extent the amount of the water in the body, as, for example, a diet consisting in large part of carbohydrates results in a considerable storage of preformed water in the body—water that is rapidly excreted upon substituting a diet in which fat predominates.[1] Changes in body-weight can accordingly be considered as a true index of body condition only when the records cover considerable periods of time.

STUDIES OF THE RESPIRATORY EXCHANGE.

While the data for the normal pulse-rate, respiration-rate, and body-temperature are, in a large number of instances, obtained under conditions that would seriously affect the results, they are infinitely more firmly established as physiological factors than is, as yet, our knowledge of the oxidation processes and energy transformations. The observations regarding the pulse-rate, temperature, respiration-rate, muscular activity, changes in body-weight, and even analyses of urine, feces, and food, do not require any especially complex or costly apparatus. If, however, to this somewhat meager balance of income and outgo it is desired to add information regarding the respiratory gases and particularly the heat transformations, none of the ordinary methods of clinical study suffice, and we must resort to elaborate and more or less costly apparatus requiring special technique for its successful use. In order to collect the respiratory gases, the patient must either breathe through a special appliance, such as nosepiece or mouthpiece, or else he must be wholly or in part incased in a large chamber. If energy transformations are to be studied, calorimetric apparatus of considerable complexity is necessary.

Early contributions.—It was very early noticed that the excretion of carbon dioxide fluctuated rapidly with variations in body activity and variations in food. Carbon dioxide as a product of combustion appeared to be an ideal quantitative index of the combustion inside the body. Physiological chemists began early to make measurements of this gaseous product, and, owing to the fact that the determination of carbon dioxide is relatively easy and accurate, the results have even to-day a practical significance.

[1] For a striking illustration of the influence of the character of the diet upon the body-weight, see Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. 175, p. 225, 1907.

Lavoisier made the earliest and most fundamental contributions to the chemistry of respiration, for although the information regarding his experiments is all too meager, there is enough evidence to warrant the belief that he had a wonderful comprehension of the respiratory processes, both qualitative and quantitative.[1] Apparently his experimental methods were so extended as to include practically all of the principles involved in the most elaborate apparatus of the present day. Not only did he use a chamber for studying the respiratory products of his subjects, but he also used special appliances attached to the mouth and nose and thus gave impetus to the extended series of observations with both of these two general methods that have continued almost without cessation since his day.

Mouth or nose appliance and respiration-chamber methods.—Of these methods, perhaps the simplest and most readily controlled is that of breathing through some special mouth or nose appliance. By the use of this method the earlier investigators were able to determine only the carbon dioxide. Later, owing to the researches of Chauveau and Tissot,[2] and Zuntz[3] and his associates, the method has been developed to such a high degree of perfection as to include both the determination of carbon dioxide and of oxygen.

The use of the respiration chamber for these studies at first gave results only for carbon dioxide. Extensive series of investigations were made by Scharling[4] and by Andral and Gavarret.[5] Later, Rubner[6] and his associates, Atwater[7] and his associates, and Sondén and Tigerstedt[8] used the chamber principle for determining carbon dioxide during long experiments. Finally, Jaquet[9] developed a chamber type of apparatus in which the oxygen could be determined directly. The description of this apparatus was shortly followed by a description of the respiration calorimeter formerly at Wesleyan University, Middletown, Connecticut, this apparatus being devised to measure not only the carbon dioxide but also the oxygen.[10] Aside from this last-mentioned apparatus, no apparatus had been equipped with appliances for measuring heat, with the exception of the Pashutin respiration calorimeter, elaborated and modified by

[1] For an interesting presentation of some of Lavoisier's researches in physiological chemistry, including illustrations of apparatus reproduced from the original sketches of Madame Lavoisier, see Edouard Grimaux, Lavoisier, 1743–1794, Paris, 1899, pp. 119 and 129.

[2] Chauveau and Tissot, Comptes rendus, 1899, **129**, p. 249.

[3] See detailed description of the Zuntz-Geppert apparatus by Magnus-Levy: Archiv f. d. ges. Physiol., 1895, **55**, p. 1.

[4] Scharling, Ann. der Chem. und Pharm., 1843, **45**, p. 214; also Ann. de Chim. et de Phys., 1843, ser. 3, **8**, p. 478.

[5] Andral and Gavarret, Ann. de Chim. et de Phys., 1843, ser. 3, **8**, p. 129.

[6] Rubner, Die Gesetze des Energieverbrauchs bei der Ernährung, Leipsic and Vienna, 1902.

[7] Atwater and his associates, U. S. Dept. Agr., Office Expt. Stas. Buls. 44, 63, 69, 109, and 136, 1897–1903.

[8] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, pp. 1–224.

[9] Jaquet, Verhandl. Naturf. Gesellsch., Basel, 1904, **15**, p. 252.

[10] Atwater and Benedict, Carnegie Institution of Washington Publication No. 42, 1905.

Likhatscheff,[1] but unfortunately used for but very few experiments. With the Pashutin respiration calorimeter, both carbon-dioxide elimination and heat production could be determined; the oxygen was not determined directly, but by difference. The perfected apparatus, formerly at Wesleyan University, therefore, is the only one previously constructed that makes possible the simultaneous determination of the carbon-dioxide elimination, oxygen consumption, and heat production.

As the number of physiological factors measured increases, the difficulties of manipulation and the cost increase enormously; consequently we find that the extent to which the different forms of apparatus are distributed is inversely proportional to the cost of installation, the difficulty of manipulation, and the number of factors simultaneously measured. This is especially unfortunate, since it is also true that the value of the results obtained increases with the number of factors simultaneously determined. Thus, in experiments in which carbon dioxide alone is determined, while the research is a distinct contribution to physiological chemistry, it has by no means the value that it would have if oxygen were simultaneously determined; and likewise the value of experiments in which carbon dioxide and oxygen are determined is enormously increased by having simultaneous determinations of heat.

The expense of the large respiration chambers, such as those of Pettenkofer,[2] Sondén and Tigerstedt,[3] and the Wesleyan University chamber,[4] has precluded the general use of this type of apparatus. To supplement the researches with these large chambers and to provide an apparatus that is at once semi-portable, accurate, and relatively inexpensive, Speck,[5] Chauveau and Tissot,[6] and Zuntz[7] have made modifications of earlier types of apparatus for studying the respiratory exchange by an examination of the expired air.

Limitations in the use of mouth or nose appliance method.—These various modifications, although yielding excellent results in the hands of the originators and associates trained in their laboratories, have not yielded as satisfactory results in the hands of physiological chemists in general as were at first hoped for. It is indeed fortunate that most of the published researches carried out with these different forms of apparatus were those undertaken either by Speck, Zuntz, and Chauveau and Tissot in person, or by their associates; consequently, the results of their experiments are, for the most part, as accurate as can be expected with apparatus of this general type.

With this method of studying the respiratory exchange, it is necessary that the subject should lie quietly breathing through a mouthpiece or nosepiece,

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[1] Likhatscheff, Production of heat of healthy man in the condition of comparative rest (Dissertation, Russian), St. Petersburg, 1893.

[2] Pettenkofer, Ann. der Chem. und Pharm., 1862, Supp. Bd. 2, pp. 1–52.

[3] Sondén and Tigerstedt, *Loc. cit.*

[4] Atwater and his associates, *Loc. cit.*

[5] Speck, Physiologie des menschlichen Athmens, Leipsic, 1892, p. 7; Schriften der Gesellsch. zur Beförderung der ges. Naturwissensch. zu Marburg, 1871, 10.

[6] Chauveau and Tissot, *Loc. cit.*

[7] Zuntz, *Loc. cit.*

with the greatest possible muscular relaxation, and the experiments are for the most part of but a few minutes' duration. For studying specific problems in the chemistry of digestion such experiments are of incalculable value. For throwing light on the normal metabolism of man they have but little value, as these men were abnormally quiet, rarely asleep, and with the greatest enforced muscular relaxation. No conditions existing in ordinary life approximate this except, perhaps, the time in bed when not asleep.

Furthermore, the most satisfactory and valuable researches with this type of apparatus have been made on men who were trained subjects. As early as the investigations of Speck,[1] it was clear to him that results were obtained on others only after long painstaking training in breathing through the mouthpiece. Some of Zuntz's associates, more venturesome, have used the apparatus on hospital patients and presumably have considerable confidence in the accuracy and value of the results thus obtained. It is admitted by all, however, that respiration through a mouthpiece is not normal and that the subjects have a considerable sense of restraint. On the other hand, it may be contended by some that the confinement inside the respiration chamber may likewise produce a feeling of restraint. It has been our experience (and this is wholly in accord with the experience of the Scandinavian investigators and of Rubner, and Pettenkofer and Voit) that the time required to accustom a person to life inside the respiration chamber is rarely more than an hour or two. Usually the subjects are comfortably seated, reading, and suffer no discomfort. For the study of the metabolism of normal man it is obvious that any feeling of discomfort, strain, forced muscular relaxation, or other artificial condition, must be minimized. From our extensive experience, both with respiration appliances, and with the chamber method, we feel confident in saying that the conditions are infinitely more normal with the respiration chamber than with the usual device for mouth or nose breathing.

In an attempt to render more normal and less painfully annoying the breathing through special appliances, an improved form of nosepiece has been developed in this laboratory[2] that can be worn for considerable periods of time without discomfort and has given results that approach the nearest to normal of any form of breathing appliance with which we are at all familiar.

With the improved methods for studying metabolism, investigators have made a large number of experiments on normal, healthy men, in an attempt to provide sufficient scientific basis for subsequent studies of men in disease. A knowledge of the respiratory products is of incalculable advantage in determining the nature of the metabolism as well as the total metabolism. Indeed, many investigators have used the carbon-dioxide production and oxygen consumption to compute the total metabolism of normal man.

Of the two methods for studying the total metabolism, and particularly the respiratory exchange, namely, the one in which the subject remains inside of a

[1] Speck, *Loc. cit.*, p. 215.
[2] Benedict, Amer. Journ. Physiol., 1909, **24**, p. 345.

large respiration chamber and, so far as the mechanics of respiration are concerned, is substantially under no abnormal influence, the other in which the products of respiration are conducted through a mouthpiece, nosepiece, or mask, the latter has been used in by far the greater number of instances.

NORMAL ACTIVITY RESTRICTED BY THE CONDITIONS OF EXPERIMENTS.

Without attempting to go into a detailed discussion of the relative advantages of the chamber method when compared with the methods involving the use of special breathing appliances, it may be said that the abnormal respiration resulting from the insertion of special appliances into the nostrils, and particularly into the mouth, may in part be compensated by the fact that the experiments are of short duration, and hence the subjects can live normally between experiments, and move about as much as desired. When the subject is confined inside the respiration chamber, on the other hand, it is necessary to remain there for many hours, usually with enforced quiet and diminished muscular activity. In neither case can the metabolism, strictly speaking, be considered as determined under normal conditions. The daily activity of the average man includes almost invariably some outdoor exercise, even if no more than walking to and from his place of business. It also involves more or less activity about the house or dwelling-place, in walking from one room to another, dressing and undressing, partaking of the different meals, and the innumerable little items of daily life. In the respiration chamber these are in large part omitted. Consequently, in all of these studies it is obvious that the metabolism is considerably less than that which would be found were the studies made under absolutely normal conditions. In both methods of experimenting, muscular activity is at the minimum.

It has been found, moreover, that even with experiments in which the gross muscular activity appeared to be more or less constant from day to day, the minor muscular movements, such as moving about in the chamber, crossing the arms or legs, reading a book and turning its pages, result in a considerable variation in the metabolism of so-called resting men. Hence it is clear that in these experiments, in which the muscular activity is confined to the minor muscular movements, the metabolism must be considerable less than that of a man about his ordinary daily occupation, even if his work does not call for sustained muscular effort.

Nearly all of the appliances for studying the respiratory exchange, either the chamber or the nose and mouth breathing type, do not permit of any major muscular movements, but there is one noticeable exception to this, *i. e.*, the large respiration chamber of Sondén and Tigerstedt in Stockholm, an apparatus that has recently been duplicated by Tigerstedt[1] in Helsingfors. The chamber is of sufficient size to permit a person, or a number of persons, to move about with considerable freedom. So far as the published reports of

[1] Tigerstedt, Skand. Archiv f. Physiol., 1906, 18, p. 298.

the investigators using these two chambers are concerned, there have not been as yet any records of experiments in which there was continued muscular activity of the subject approximating that of the ordinary routine of man about a dwelling house. The apparatus has been used in most instances for studying the influence of muscular work, particularly static work, upon the metabolism, and but few of the results reported by these investigators can be used as indices of the normal 24-hour metabolism.

METABOLISM DURING SPECIFIC ACTIVITIES AND MOVEMENTS.

During sleep.—In general, any type of respiration chamber makes it wholly impracticable to attempt to carry out 24-hour experiments in which a subject lives with the same amount of muscular activity as if he were about his ordinary life. There remains, therefore, at the present time the only alternative of selecting such portions of different experiments, if possible made with the same subject, as will enable us to obtain a correct impression of the metabolism during separate muscular activities, represented by those of the daily life. Of these by far the simplest, and fortunately thus far the most accurately determined, is the metabolism during sleep. A large number of experiments have been made with the respiration calorimeter formerly at Wesleyan University, at Middletown, Connecticut, in which the subjects rested with a reasonable degree of comfort, and during the night were, in the majority of instances, sleeping under fairly normal conditions. Up to the present time the results of these experiments, although they have been presented in a number of reports, have never been collected so as to throw definite light upon the metabolism of normal, healthy men during sleep.

During waking hours, influenced by rest, by variations in weight or height, and by act of undressing and dressing.—In order to obtain more satisfactory results regarding the metabolism during rest, awake, a number of experiments were made in which the conditions were those of comparative rest, the subject remaining seated in an arm chair for the most part or all of a period of 3 to 8 hours. In some experiments food was taken in moderate amounts during the period itself; in others, the experiment was made either immediately after a meal, or 12 hours or more after the last meal. A few other experiments were made in which the subjects remained inside the chamber for 24 hours and the results are useful for comparison with the previously published experiments.

Another important point that has as yet been too little emphasized in the reports of American investigators in this line is the influence of variations in body-weight upon the metabolism. Accordingly, certain experiments were so designed as to include the study of the metabolism of men of considerable body-weight and also of men of unusual height.

The average normal man dresses and undresses at least once a day. This involves considerable muscular activity for a greater or shorter length of time and his body is exposed to colder environment than the layer of air usually

existing between clothing and body. Some data regarding the energy transformation during dressing and undressing are of distinct value in making up the total energy transformations during the day. A number of experiments to emphasize this point were made and are herewith reported.

Opening food aperture.—In connection with the experiments with the respiration calorimeter, especially those in which the subject remained seated in a chair, one series of movements which called for a large amount of muscular activity was the motion of rising from the chair, taking one or two steps to the opening inside of the calorimeter through which food and drink are passed, opening this door, removing the containers for food and drink, closing the door, and returning to and sitting down in the chair. Inasmuch as this operation played a very important rôle in a number of experiments, several experiments were designed to study the metabolism and energy transformations during the time required.

SPECIFIC OBJECT OF EXPERIMENTS HERE REPORTED.

A large number of experiments made by Atwater and his associates were planned specifically to study some problem dealing with muscular work. The diets were large and one-sided and we find difficulty in considering these experiments as being typical of normal resting metabolism. The extensive series of observations on metabolism during inanition[1] is open to the same objection. The fact that there is a marked depletion of the store of glycogen on the first day of fasting is of itself conclusive evidence that the experiments can not be considered as normal metabolism. From time to time in connection with the experimental researches with the respiration calorimeter already reported during the past few years, we have, as suggested above, made a large number of short experiments with different individuals living under what were called normal conditions, in order to study the normal resting metabolism, and the data thus far obtained warrant presentation at this time. It is hoped ere long to supplement these with more data regarding the metabolism of women and children. It has been impossible to extend this series of observations so as to include many people of widely different ages, and most of the experiments have been made with young, healthy men—college students and laboratory assistants. A few experiments were made with women students. The reports of the American researches in the calorimetry of man have been very extended and may be found in a number of the publications of the Office of Experiment Stations of the United States Department of Agriculture and of the Carnegie Institution of Washington. The results are of such general interest that it seemed advisable to include them in a discussion of the results obtained by the special series of experiments here reported.

On the other hand, the almost instantaneous effect of the ingestion of food on metabolism has been deemed of sufficient importance to justify a special

[1] Benedict, Carnegie Institution of Washington Publication No. 77, 1907.

research, and evidence is at present being accumulated on this most important point. It is hoped that a report will be issued in the near future. Consequently, in this discussion no attempt will be made to introduce the discussion of the influence of the ingestion of food, the specific dynamic action of the foodstuffs, or the so-called work of digestion.

METHOD OF EXPERIMENTING.

The experiments here reported were all made with the respiration calorimeter formerly at Wesleyan University, Middletown, Connecticut. The apparatus has been described in detail in a number of places.[1] Suffice it to say here that the apparatus is a respiration chamber with calorimetric features. The chamber is air-tight, with a cubical content of about 5 cubic meters, and the ventilating air-current is caused to pass through a series of purifiers by which the water-vapor and carbon dioxide are removed. The air is then returned to the chamber, the deficiency in oxygen being made up by admitting oxygen from a cylinder of the highly compressed gas. By noting the increase in weight of the absorbers for water-vapor and carbon dioxide and the loss in weight of the oxygen cylinder, the carbon dioxide and water-vapor given off and the oxygen absorbed can be determined with a certain amount of accuracy. Finally, corrections are made for variations in the composition of the air remaining in the chamber and the figures thus corrected are the true values for the carbon-dioxide production, water-vapor elimination, and oxygen absorption.

As a calorimeter, the chamber is surrounded by walls which prevent the radiation of heat. Special precautions are taken to maintain the outer walls at the same temperature as the inside of the calorimeter by arbitrarily heating or cooling the air adjacent to the outer metal wall. By so doing all passage of heat into or out of the chamber through the walls is prevented. The major portion of the heat eliminated by the subject is brought away by a current of cold water passing through an absorber system inside the chamber. The temperature of the water as it enters and leaves and the mass of water are carefully recorded, and from these data the amount of heat brought away can be accurately computed. To the heat brought away in this manner must be added the heat required to vaporize the water from the skin and lungs of the subject. Consequently, the total heat of vaporization must be known. Multiplying the total water vaporized by the factor 0.586, the heat required to vaporize the water is computed, and this added to the heat brought away by the water-current gives the true measure of the heat eliminated by the subject.

For purposes of extreme accuracy the heat elimination is not satisfactory, since there may be a considerable storage or loss of heat from the body by

[1] Atwater and associates, U. S. Dept. Agr., Office Expt. Stas. Buls. 63 and 136, 1899 and 1903; Benedict and Milner, *ibid.*, Bul. 175, 1907; Atwater and Benedict, Carnegie Institution of Washington Publication No. 42, 1905.

virtue of noticeable changes in body-temperature. A rise in body-temperature of 1° in a body weighing 70 kilos results in a storage of about 60 calories. It is necessary, therefore, to know the body-temperature with great accuracy, and this is measured by means of an electrical-resistance thermometer placed in the rectum. The body-weight is determined from time to time by scales outside of the chamber, from the platform of which is suspended the chair in which the subject sits inside the chamber.

SCOPE AND ROUTINE OF PRESENT SERIES OF EXPERIMENTS.

The experiments here reported are of widely varying nature. The majority of them lasted but 6 or 7 hours and were made during the daytime. In a few others, the subject remained inside of the chamber some 24 or more hours. In the long experiments, the subject usually entered the chamber the night before the experiment proper began. As a result of many years' experimenting, it has been deemed advisable to begin the experimental day at 7 a. m., at which time it is assumed that the body-temperature, general activity, and mass of body-material remains more nearly the same from day to day than at any other hour. After entering the chamber, the subject goes to bed and is not allowed to rise until the next morning a few moments after 7 o'clock. The greater part of the day is spent in sitting in the chair reading or writing, or occasionally lying on the bed, and where food is eaten it is taken in regular periods and in regular amounts. The urine and feces are properly collected and analyzed. In the short experiments, where only data regarding normal waking metabolism were desired, it was deemed unnecessary to have the subjects remain so long a period inside of the chamber, and the plan of experimenting was so modified as to enable us to secure short experiments with a number of subjects rather than a long experiment on one subject. In these short experiments the subject entered the chamber in the early forenoon and as soon as thermal equilibrium was established in the chamber the experiment proper began. In a number of experiments food was given during the experiment itself; in others no food was taken. In the detailed statistics of the experiments will be found all the data regarding the diet, the time at which food was taken, the muscular movements, and similar physiological data.

Study of nitrogen balance in these experiments impracticable.—While it may seem somewhat surprising that in the discussion of any series of experiments intended as a study of the normal metabolism of man, the data regarding the nitrogen output in urine and feces are not included, nevertheless it has been found that unless the subject remains upon a relatively constant diet for at least 3 or 4 days previous to the experiment the nitrogen elimination during an experiment of only 6 to 8 hours' duration has relatively very little significance. Indeed, the common assumption that nitrogen in urine represents the disintegration of an equivalent amount of protein during the time of

experimenting has been seriously questioned. There may be a distinct interval elapsing between the disintegration of protein and the elimination of nitrogen, and, indeed, the excretion of carbon dioxide resulting from such disintegration.

Protein katabolism and nitrogen balances are subjects which can be dealt with outside of and independent of a respiration calorimeter. The large amount of chemical analysis and routine work involved in a series of experiments as extensive as is this, made it practically impossible to simultaneously engage in a long study of the nitrogen metabolism. Furthermore, it seemed more desirable to obtain results on a relatively large number of subjects than to make duplicate experiments or a large number of experiments with the same subject. Obviously, the difficulties attending the prescription of a preceding diet and obtaining rigid adherence thereto for several days before an experiment made such preliminary supervision impracticable. The experiments presented in this report, therefore, do not purport in any way to throw light upon the normal nitrogen metabolism of man, and but few figures are given with regard to the urinary analyses. We have to deal here chiefly with the gross metabolism as indicated by the vaporization of water, carbon-dioxide production, oxygen absorption, and heat elimination and production.

PART 2. STATISTICS OF EXPERIMENTS.

The experiments for which data are reported in this publication were made with 51 different subjects. Statistics of the age, height, and weight of these subjects are presented in summary form in table 1, the age being for the time as near as practicable to the average date of the experiments with each individual, and the weight being the average without clothing in each case. The actual weights of any subject may vary within considerable limits, according to the number of experiments and the lapse of time between experiments.

TABLE 1.—*Statistics of age, height, and average weight of subjects.*

Experiment No.	Subject.	Age.	Height.	Weight.	Experiment No.	Subject.	Age.	Height.	Weight.
			Cm.	*Kilos.*				*Cm.*	*Kilos.*
101	H. F.....	53 yrs.........	168	71.7	150-153	H. R. D..	17 yrs. 10 mos.	171	58.2
102	W. O. A..	59 yrs.........	168	84.8	154	J. H. K..	54 yrs. 2 mos.	164	56.1
103-108	B. F. D..	23 yrs.........	170	66.2	155-157	H. C. K..	21 yrs. 10 mos.	181	73.0
109	J. C. W..	26 yrs.........	178	75.0	158	H. G.....	22 yrs. 5 mos.	160	49.2
110	J. T. H...	20 yrs.........	170	56.0	159	H. L. W..	26 yrs. 11 mos.	164	51.6
111	C. F. B...	16 yrs. 7 mos.	170	62.2	160	F. E. R..	20 yrs. 5 mos.	168	52.9
112-113	T. M. C..	26 yrs. 7 mos.	166	50.5	161	F. N. C..	19 yrs. 1 mo..	168	57.4
114-115	H. C. M..	27 yrs. 6 mos.	166	86.3	162	H. C. A..	21 yrs. 4 mos.	172	59.0
116-117	S. C. D...	31 yrs. 2 mos.	178	74.9	163	N. M. P..	21 yrs. 2 mos.	179	69.8
118-120	B. N.....	16 yrs. 2 mos.	168	46.4	164	J. A. R...	23 yrs. 6 mos.	180	59.0
121	F. L. T...	25 yrs. 7 mos.	192	64.3	165	H. D. A..	21 yrs. 5 mos.	181	67.2
122	W. R. L..	24 yrs. 6 mos.	198	74.9	167	A. M.....	21 yrs. 6 mos.	175	66.6
123-124	W. H. L..	31 yrs. 7 mos.	174	63.2	168	D. R. F..	23 yrs.........	173	62.6
125	F. W. H..	33 yrs. 8 mos.	173	58.4	169	J. N. T...	21 yrs. 10 mos.	173	63.5
126	J. R......	22 yrs. 10 mos.	183	69.2	170	C. A. R..	18 yrs. 10 mos.	174	59.7
127	R. D. M..	35 yrs. 9 mos.	178	70.4	171	A. G.....	24 yrs.........	170	63.3
128-129	R. A. M..	31 yrs. 11 mos.	166	65.0	172	G. G. R..	19 yrs. 10 mos.	178	77.2
130, 166	H. L. K..	23 yrs. 8 mos.	166	56.3	173	J. V. C...	22 yrs.........	173	63.1
131-132	H. A. P..	27 yrs........	180	64.3	174	E. M. S..	27 yrs.........	175	64.4
133	W. E. D..	20 yrs. 4 mos.	179	74.4	175	G. E. H..	27 yrs.........	179	63.1
134-135	C. R. Y..	20 yrs.........	170	67.8	176	G. H. H..	21 yrs. 3 mos.	163	51.7
136	F. G. B..	35 yrs.........	183	83.2	177	J. W. H..	29 yrs.........	175	61.2
137-144	A. H. M..	24 yrs. 3 mos.	179	65.3	178	G. W. S..	20 yrs.........	173	50.7
145	H. A.....	18 yrs. 10 mos.	170	64.1	179-180	C. F. S...	21 yrs. 7 mos.	161	62.6
146	D. W....	22 yrs. 2 mos.	180	75.6	181-183	G. E. B..	26 yrs. 2 mos.	157	57.2
147-149	A. L. L..	24 yrs. 10 mos.	166	67.5					

METABOLISM EXPERIMENT No. 101.

Subject, H. F., March 23–25, 1903. Age, 53 years; height, 168 cm.; weight without clothing, 71.7 kilos.

The subject of this experiment was a man whose dietetic habits had attracted much attention and whose continued practice of excessive mastication had, he believed, resulted in a greatly increased economy in the use of food in the body. As a result of his peculiar dietetic customs, this subject believed he could exist on a much smaller amount of nitrogenous material, as well as of total food, than was consumed by an ordinary man of like body-weight and muscular activity. These impressions were at that time partly substantiated

by a number of short experiments made on him in different physiological laboratories, but while numerous observations regarding his body-weight and strength had been made, as well as urine and fecal analyses, there had been no opportunity to study his gaseous exchange. Neither his total metabolism nor his carbon-dioxide production had previously been studied, and hence there was no evidence regarding his total requirements for energy. It seemed especially interesting, therefore, to make a study of this subject and find what were his energy requirements as compared with other individuals of like body-weight and activity.

The calorimetric features of this apparatus had unfortunately been seriously disturbed in the process of alteration from an open-circuit respiration apparatus of the Pettenkofer type to a closed-circuit apparatus of the Regnault-Reiset[1] type and hence we were unable to secure satisfactory heat measurements during this experiment. However, the general widespread interest in the metabolism of this subject warrants our reporting the results for the nitrogen and carbon balance. A subsequent experiment with this subject, in which the carbon-dioxide and water-vapor elimination, oxygen consumption, and heat production were simultaneously determined, has been published in detail elsewhere.[2]

The subject entered the respiration chamber in the evening of March 23, 1903, and regular observations began at 1 a. m., March 24. Five 6-hour periods were obtained with this man, the experiment ending at 7 a. m., March 25. The diet for several days before had not been unlike that taken during the experiment, judging by the general impression of the subject, although he was not under observation at that time. The analyses of the urine had substantiated this view, at least so far as the nitrogenous ingredients of the diet were concerned. The usual separations of the urine in different periods of the day, four 6-hour periods, were made. It was not considered practicable, however, to attempt to separate the feces as the experiment was so short.

Program and record of activity.—The subject was accustomed to keeping very irregular hours, retiring early and frequently rising in the middle of the night, in fact, following no definite program. Hence, while all previous experiments had been made with a regular program, it was here considered advisable to allow this subject to follow his own inclinations with regard to sleeping and moving about, the only stipulation being that he should consume his food between 7 a. m. and 11 p. m.

The amount of muscular activity indulged in by this subject was not recorded with as much detail as in the subsequent experiment, and therefore a complete interpretation of the metabolism from period to period is not possible. The records as made by the different observers have been compiled and are given herewith.

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[1] Regnault and Reiset, Ann. de Chim. et de Phys., 1849, ser. 3, 26.
[2] Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. 175, 1907, p. 84.

Movements of subject from Mar. 24, 1 a. m., to Mar. 25, 7 a. m., 1903—Metabolism experiment No. 101.

March 24.		*March 24.*		*March 25.*	
A. M.		P. M.		A. M.	
$1^h 14^m$	moved in bed.	$3^h 54^m$	rose.	$12^h 44^m$	lying down (sleeping?).
2 38	moved in bed.	4 15	at food aperture twice to take out and put in articles.	3 06	made up bed.
6 10	moved in bed.	4 22	walking about.	3 08	in bed.
7 00	arose, dressed and made bed.	4 48	standing up.	4 24	sat up in bed.
P. M.		5 40	at food aperture to pass out articles.	4 52	moving.
$1^h 05^m$	at food aperture twice to put in and take out articles.	7 00	at food aperture to take out articles, ate supper.	5 00	sitting up in bed.
1 16	ate dinner.	10 22	at food aperture twice to put in and take out articles.	5 32	sitting up.
1 52	lying down.			5 38	writing on typewriter.

Subsequent to his stay in the calorimeter the subject prepared from his notes a program, which is given herewith.

March 24.	1 a. m. to 7 a. m.	Complete rest.
	7 a. m. to 1 p. m.	Arranging furniture 30^m; typewriting 5^h.
	1 p. m. to 7 p. m.	Reading from 1^h to $1^h 30^m$ p. m.; first meal, $1^h 30^m$ to $1^h 45^m$ p. m.; alternate rest and typewriting to end of period.
	7 p. m. to 1 a. m.	Slept $2^h 30^m$; ate second meal of the day and rested 30^m; wrote on typewriter rest of time.
March 25.	1 a. m. to 7 a. m.	Slept $2^h 30^m$; read 30^m; rested 30^m; wrote on typewriter $2^h 30^m$.

This schedule as given by the subject indicates a total of over 11 hours of work (typewriting) but no definite record regarding the amount of work accomplished was obtained. A small portable machine, usually carried in the subject's traveling bag, was used. The program shows a marked difference in the muscular activity between the first period (1 a. m. to 7 a. m., March 24) and the last period (1 a. m. to 7 a. m., March 25). In the first there was complete rest and in the last he was relatively active. This schedule is of interest in interpreting the metabolism of this subject later on. While writing with the typewriter he sat on the bed and occasionally, when he was about to move around in the chamber, the machine was placed on the floor.

Pulse and body-temperature.—Fragmentary data regarding the pulse and body-temperature (with clinical thermometer in the rectum) are given herewith.

Pulse-rate per minute:	
Mar. 23, $10^h 23^m$ p. m.	71
11 42 p. m.	64
Rectal temperature:	°F.
Mar. 24, $7^h 00^m$ a. m.	97.9
4 15 p. m.	98.9
7 00 p. m.	99.2
Mar. 25, 7 00 a. m.	97.9

FOOD.

During this experiment the subject partook of the simple diet that he was wont to use during experiments on himself. It consisted of milk, prepared cereal, and maple sugar. The total amount of food eaten corresponded to but

6.38 grams of nitrogen and 1496 calories of energy. Of the nitrogen, 4.06 grams were in the milk and 2.32 grams were in the prepared cereal. Thus there was a predominance of protein of animal nature. As the experiment could last at best but some 30 hours and there could be no satisfactory separation of feces, it was not considered advisable to make a chemical investigation of the foods, so the data regarding the percentage composition and heat of combustion per gram are in part assumed and in part determined.

TABLE 2.—*Percentage composition and heat of combustion of food—Metabolism experiment No. 101.*

Kind of food.	Nitrogen.	Carbon.	Fat.	Carbohydrates.	Heat of combustion per gram.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*Cals.*
Milk	[1]0.58	7.83	[1]4.5	5.0	[1]0.815
Breakfast cereal	[1]1.93	44.00	1.4	75.0	[1]3.988
Maple sugar	....	[2]37.24	...	[2]87.5	[2]3.432

[1] Actually determined during this experiment.
[2] Values obtained from a later experiment.

TABLE 3.—*Weight, nitrogen, and energy of food—Metabolism experiment No. 101.*

[Amounts consumed by the subject.]

Kind of food.	Weight.	Nitrogen.	Energy.
Dinner.	*Grams.*	*Grams.*	*Cals.*
Milk	400	2.32	326
Breakfast cereal	70	1.35	279
Maple sugar	50	....	172
Total	520	3.67	777
Supper.			
Milk	300	1.74	245
Breakfast cereal	50	0.97	199
Maple sugar	80	....	275
Total	430	2.71	719
Total for day	950	6.38	1496

TABLE 4.—*Total nutrients and energy of food—Metabolism experiment No. 101.*

Kind of food.	Nitrogen.	Fat.	Carbohydrates.	Energy.
	Grams.	*Grams.*	*Grams.*	*Cals.*
Milk	4.06	31.5	35.0	571
Breakfast cereal	2.32	1.7	90.0	478
Maple sugar	....	....	113.7	447
Total	6.38	33.2	238.7	1496

These results are given in table 2. Two meals were taken on March 24, dinner at $1^h 16^m$ p. m. and supper at 7 p. m. A subdivision of the food, showing the nitrogen and energy of these two meals, is given in table 3.

The total nutrients and energy of the food were obtained for the subsequent computation of the total metabolism and are given in table 4 as the results for 24 hours.

URINE.

For 3 days prior to entering the chamber the subject had saved the urine, but of these days only the last was during actual observation in the laboratory. The total amount of nitrogen was determined on each sample. During the sojourn inside the respiration chamber the collection of urine was subdivided

TABLE 5.—*Weight, specific gravity, and nitrogen of urine—Metabolism experiment No. 101.*

Date.	Period.	Amount.	Specific gravity.	Nitrogen.
1908.		*Grams.*		*Grams.*
Mar. 21-22	7 a.m. to 7 a.m.[1]	731.5	1.0160	5.26
Mar. 22-23	7 a.m. 7 a.m.[1]	853.0	1.0155	6.18
Mar. 23-24	7 a.m. 7 a.m.	417.8	1.0300	5.85
Mar. 24-25	7 a.m. to 1 p.m.	89.0	1.0330	1.26
	1 p.m. 7 p.m.	110.8	1.0285	1.85
	7 p.m. 1 a.m.	100.8	1.0350	1.83
	1 a.m. 7 a.m.	88.7	1.0335	1.48
Total		388.3	....	6.42
Total by composite[2]		388.3	1.0320	6.45

[1] Presumably for total 24 hours. Subject made collection of urine before coming to the laboratory.
[2] Energy 62 calories, determined.

into 4 periods of 6 hours each as is customary in experiments of this nature. As a check on the accuracy of the analyses the total nitrogen for each of these periods was determined and also in a composite sample. A portion of the urine was dried and burned in a calorimetric bomb to determine the heat of combustion. This was found to correspond to 0.160 calories per gram and the total energy of the urine for the day, therefore, was 62 calories. The results are given in table 5.

TABLE 6.—*Water vaporized—Metabolism experiment No. 101.*

Date and period.	(a) Weight in chamber at end of period.	(b) Gain (+) or loss (−) from preceding period.	(c) Weight absorbed from outcoming air.	(d) Corrected weight vaporized. (b+c)
1908. March 23-24:	*Grams.*	*Grams.*	*Grams.*	*Grams.*
7 p.m. to 1 a.m.	46.18	....	....	....
1 a.m. 7 a.m.	40.02	− 6.16	196.46	190.3
March 24-25:				
7 a.m. to 1 p.m.	37.72	− 2.30	204.59	202.3
1 p.m. 7 p.m.	39.92	+ 2.20	188.43	190.6
7 p.m. 1 a.m.	36.47	− 3.45	191.87	188.4
1 a.m. 7 a.m.	34.81	− 1.66	172.08	170.4
Total, 7 a.m. to 7 a.m.	....	− 5.21	756.97	751.7

ELIMINATION OF WATER-VAPOR.

The amount of water vaporized in the different periods during the experiment is given in table 6. An examination of the residual amounts of water-vapor inside the chamber shows that there was a slight tendency for the air

to become dryer as the experiment progressed. The total amounts of water vaporized likewise tend to fall off somewhat. Since the volume of air inside the chamber is not far from 4900 liters, and at a temperature of 20° this would, when saturated, contain 84 grams of water, it would seem that the humidity was not far from 45 per cent. As this was one of the earliest experiments made with this apparatus in its modified form, it is extremely difficult to determine with the greatest accuracy the source of water vaporized inside the chamber, for it may have come partly from the lungs of the subject, partly from the skin, and partly from the bed and furniture. The subsequent development of technique has made it possible in the majority of experiments to weigh all the material in the chamber of a hygroscopic nature and thus apportion to a certain degree the amount of water vaporized.

ELIMINATION OF CARBON DIOXIDE.

The data regarding the carbon-dioxide elimination are summarized in table 7. As is usual in experiments of this type the amount of carbon-dioxide residual inside the chamber increased somewhat during the day and fell off noticeably during the night.

TABLE 7.—*Record of carbon dioxide—Metabolism experiment No. 101.*

Date and period.	(a) Weight in chamber at end of period.	(b) Gain (+) or loss (−) from preceding period.	(c) Weight absorbed from outcoming air.	(d) Corrected weight exhaled by subject. (b+c)
1903. March 23-24:	*Grams.*	*Grams.*	*Grams.*	*Grams.*
7 p.m. to 1 a.m.	29.87	....	....	....
1 a.m. 7 a.m.	26.38	− 3.49	120.62	117.1
March 24-25:				
7 a.m. to 1 p.m.	38.65	+12.27	176.63	188.9
1 p.m. 7 p.m.	44.46	+ 5.81	191.59	197.4
7 p.m. 1 a.m.	34.70	− 9.76	124.48	114.7
1 a.m. 7 a.m.	33.01	− 1.69	156.19	154.5
Total, 7 a.m. to 7 a.m.	....	+ 6.63	648.89	655.5

A simple calculation from the total volume of air in the chamber and the residuals as determined shows that at no time was carbon dioxide present in the chamber in amounts greater than found normally with this apparatus. As can readily be seen, the amounts of carbon dioxide given off fluctuated widely, the smallest amount being from 7 p. m. to 1 a. m., 114.7 grams, and the largest amount from 1 p. m. to 7 p. m., 197.4 grams. From the records of movements made by the subject, it is difficult to understand why the carbon-dioxide production was so low between 7 p. m. and 1 a. m.

MEASUREMENTS OF OXYGEN CONSUMED AND HEAT ELIMINATED.

Unfortunately, as the experiment with this subject was one of the first made with the apparatus so modified as to include the determination of oxygen, a

number of mishaps were encountered which prevented a satisfactory determination of oxygen, and while results were obtained for certain periods, they are not considered of sufficient value to publish, and hence they are not here presented. Fortunately, as mentioned above, we have a 3-day experiment with this subject made some 7 months later, in which the oxygen determination was most satisfactory. It is a matter of great regret that during this experiment the determinations of heat were so vitiated by errors in manipulation that no results of value were obtained.

MATERIAL KATABOLIZED IN THE BODY.

Data for calculation of the total katabolism.—The amount of food ingested, even when measured for a period of several days or weeks, can not be a true index of the energy requirement of the body as there may be considerable drafts upon the body-material or a storage of body-material during this time without any especial gain or loss in body-weight. If each gram of fat or glycogen withdrawn from his store in the body was expressed by a loss in body-weight of 1 gram this method of estimating the energy requirement would obviously hold true, but the proportion of water in the body at different times may vary to a marked degree, and especially is this so when there are noticeable changes in dietetic habits. It has been clearly shown that the ingestion of a carbohydrate-rich diet results in a storage of water in the body, while a carbohydrate-poor diet results in a noticeable loss of water. In an experiment reported by Benedict and Milner[1] the actual weight of total food consumed with a carbohydrate-rich diet covering a period of 3 days was actually much less than the total weight of food consumed in a subsequent 3-day period with a carbohydrate-poor diet containing the same amount of energy. During the latter experiment with a high-fat diet however there was a marked loss in body-weight. Consequently, in studying the dietetic requirements of different individuals, particularly the energy requirements, it is absolutely necessary either to continue the experiment for periods covering several months with accurate weighings of both income and outgo and to determine simultaneously variations in body-weight, or to make a complete metabolism experiment in which the total gaseous exchange is determined for periods of not less than 24 hours.

There had previously been many experiments on the metabolism of this subject which seemed to indicate, so far as the deductions of some of the investigators are concerned, that he could subsist on a diet containing a much smaller amount of total energy than the average man consumed in his customary diet. It was therefore of particular interest to us to make the study with this subject, although it was a matter of great regret that the oxygen and heat determinations were unsatisfactory. We were able, however, to obtain the excretion of carbon in the respiration, and nitrogen in the urine, and these, with the data of his later experiment, suffice to give us a reasonably accurate picture of his katabolism.

[1] Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. 175, p. 225, 1907.

In the calculation of the total katabolism, in experiments where the oxygen determinations are unsatisfactory, it is customary to assume that the total carbon elimination, other than the carbon from protein, is derived from fat. Since, however, the total amount of carbohydrates ingested in this diet was small and can be found with reasonable accuracy, it is perhaps not erroneous to assume that these carbohydrates were completely absorbed.

As the katabolism shows subsequently that there was a marked draft upon the body-material even under these conditions, we are correct in assuming that in all probability the total carbohydrates ingested were burned, and the chief question is whether the draft upon the body-material was met by the supply of glycogen or was wholly fat. From the experience with a large number of fasting subjects, it was found that on the first day of inanition there may be as high as 180 grams of glycogen broken down in the body. On the other hand, the subject of the experiment here reported actually stored glycogen on the first 2 days of a 3-day experiment[1] nearly identical with this experiment in plan. The muscular activity, body-weight, nature and amount of diet all being the same in both cases, it is not unreasonable to assume that he actually stored carbohydrates during this day. This possible, if not probable, storage of glycogen may be assumed as equal to 21 grams for the 24 hours, *i. e.*, an average of the storage on the first 2 days of the experiment referred to above. Under these conditions the calculation of the total katabolism becomes somewhat complicated.

For the calculation of the total katabolism, then, the following data are available:

	Grams.
Carbon dioxide as determined in respired air from 7 a. m. to 7 a. m. =	655.5
Nitrogen in urine from 7 a. m. to 7 a. m. .... =	6.45

From these two factors and the assumed storage of 21 grams of glycogen it is possible to compute with considerable accuracy the total katabolism.

Katabolism of protein.—The protein is commonly determined by multiplying the nitrogen excreted in the urine by the factor 6.0. In this experiment, therefore, the excretion of nitrogen corresponds to the disintegration of 38.7 grams of protein.

Katabolism of carbohydrate and fat.—In addition to the carbon of carbon dioxide expired, there is a certain amount of carbon in the urine. The ratio of carbon to nitrogen has frequently been determined with normal healthy men, and fortunately we have the average of the 3-day experiment made subsequently with this subject in which it was found that for every gram of nitrogen there was 0.879 gram of carbon in the urine. Hence, in this experiment, with the excretion of 6.45 grams of nitrogen there would probably be the equivalent of 6.45×0.879 or 5.67 grams of carbon in the urine.

In the carbon dioxide exhaled there are 178.8 grams of carbon. The total excretion of carbon for the day, therefore, corresponds to 178.8 grams excreted

[1] Benedict and Milner, *Loc. cit.*, p. 93.

in the respired air plus the 5.6 grams excreted in the urine, making a total of 184.4 grams. Assuming that the total carbon from the protein disintegrated is excreted and that 52.8 per cent of the protein is carbon, the disintegration of 38.7 grams of protein would correspond to the excretion of 20.4 grams of carbon. Obviously, a portion of this carbon is excreted as unburned carbon in the urine and a portion of it as carbon of carbon dioxide exhaled; but since the unoxidized portion of the urine is taken into consideration in the output, it is proper that the 20.4 grams of carbon from protein should be assumed as being entirely excreted. Since the total carbon elimination is 184.4 grams and but 20.4 grams were derived from protein, there obviously remain 164 grams to be apportioned between the katabolism of fat and of carbohydrate from food and body material.

The relatively small amount of carbohydrates ingested in these experiments leads to the perfectly proper assumption that it was entirely absorbed during the course of 24 hours, and from table 4 it can be seen that there were 238.7 grams of carbohydrates. Of this amount, it is assumed that 21 grams were deposited as glycogen in the body. Leaving out of discussion the slight differences in the carbon content of food carbohydrate and glycogen, we may conclude that the total amount of carbohydrate katabolized was

$$238.7 - 21.0 = 217.7 \text{ grams.}$$

This corresponds to 91.5 grams of carbon.[1] This carbon, together with the carbon from protein, amounts to

$$91.5 + 20.4 = 111.9 \text{ grams}$$

and hence there remain from the total excretion of 184.4 grams, 72.5 grams of carbon which are derived from fat either of food or of body. Waiving the question of difference between the percentage of carbon in food-fat and that in body-fat, and assuming the percentage of carbon in the butter-fat for the most part present in the diet of this experiment to be 75 per cent, 72.5 grams of carbon are equivalent to 96.7 grams of fat. The calculation of the total fat in the food shows that there were 33.2 grams, which, deducted from 96.7 grams, leave 63.5 grams of fat katabolized from body-material.

BALANCE OF INTAKE AND OUTPUT OF NUTRIENTS.

The gain or loss of material is shown in table 8 in which the amounts of material katabolized are those calculated as indicated above.

According to the calculations as presented in table 8, there was a gain to the body of 1.17 grams of protein, a loss of 63.5 grams of fat, and a gain of 21 grams of carbohydrate. In considering these values as thus presented it is important to note in the first place that no allowance whatever is made for the material in feces. While the earlier idea that the feces consisted in large

[1] Since fully 60 to 70 per cent of the carbohydrates ingested were in the form of mono- or di-saccharids rather than starch, it has seemed reasonable to assume that there would be on the average 42 per cent of carbon.

part of undigested material has been radically revised in the past 10 years, there still remains the fact that the material in the feces can be considered as not available to the body and as an excretion. It was impracticable in this experiment of only 24 hours' duration to separate the feces. From a large number of experiments made with a simple diet like that partaken of in this experiment it has been found that not far from 93 per cent of the protein, 97 per cent of the fat, and 98 per cent of the carbohydrates is absorbed. If, therefore, allowance is here made for the amounts determined in a normal excretion of feces, the apparent gain of protein will probably become a loss, the loss of fat will be somewhat greater than here indicated, and the apparent gain of carbohydrates will be slightly less.

TABLE 8.—*Gain or loss of body material—Metabolism experiment No. 101.*

Material.	Protein.	Fat.	Carbohydrate.
	Grams.	*Grams.*	*Grams.*
Katabolized	38.70	96.7	[2]217.7
In food	[1]39.87	33.2	238.7
Gain or loss	+1.17	−63.5	+21.0

[1] N × 6.25.
[2] Assumes carbohydrate katabolized to be same in amount as carbohydrates absorbed less 21 grams of glycogen stored.

TRANSFORMATION OF ENERGY.

Heat production.—The energy of the material katabolized in the body may be computed directly from the measurements of the katabolism and the well-known factors which represent the heat of combustion of the protein, fat, and carbohydrate. The calculation, then, may be expressed thus:

	Calories.
Protein	$38.7 \times 5.65 = 219$
Fat	$96.7 \times 9.54 = 923$
Carbohydrate	$217.7 \times 4.19 = 912$

The total potential energy of material katabolized in the body was therefore 2054 calories. Of this a certain portion, however, was not actually transformed into heat for the actual determination of the potential energy of the urine showed that there was unoxidized material in the urine equivalent to 62 calories. Therefore, the actual energy transformation resulting from the katabolism of material in the body was 1992 calories, and this represents very nearly the total heat production for the day for this subject.

Balance of intake and output of energy.—The potential energy of the food, making no allowance for feces, was 1496 calories, and hence there was a demand upon body-fat for energy to supply the necessary amount for the day. The large number of assumptions made necessary by the deficient data of this experiment do not warrant further refinements, but in general terms it may be said that there was a draft upon the body for sufficient material (fat) to supply the deficiency in available energy of the food amounting in round numbers to 550 calories.

Comparison with results in similar experiments.—The 3-day experiment, made subsequent to this and published elsewhere, is much more detailed, and it is of interest to compare these days with the experiment in hand. In this comparison it is necessary to note that on the 3 days of the experiment already published the bodily activity did not exceed, if indeed it was not considerably less than, the bodily activity during this experiment. While the impression of the subject that he had worked on the typewriter for 12 hours is unquestionably too large, and the work on the typewriter was more or less desultory in nature, it is probably fair to assume that the work thus done was not more than the equivalent of 4 or 5 hours' continuous typewriting by a person accustomed to the use of the machine. Experiments made subsequent to this experiment have shown that the amount of energy above the resting metabolism required to write 1600 words per hour on the typewriter is not far from 25 calories, and hence we may assume that the work of typewriting in this case involved an expenditure above the resting metabolism of not much more than 25 calories per hour.[1]

Accuracy of indirect method.—For purposes of accurate comparison of the two experiments with this subject, the only index of which we can be perfectly sure is the carbon elimination. This is a reasonably accurate index of the metabolism of this subject, inasmuch as during this experiment he was using a diet somewhat deficient in energy but containing a large proportion of carbohydrate, and hence the dietetic conditions in the two experiments did not differ widely. While, therefore, the actual heat production by direct calorimetry is missing in this experiment, the heat production by indirect calorimetry is known with reasonable accuracy, and although frequently there are wide discrepancies between the direct and indirect calorimetry when comparisons are made in short periods, the values for 24-hour periods agree very satisfactorily. This is true even under such adverse conditions for experimenting as those obtaining during fasting, where the difference in the nature of the composition of the body substance at the beginning and end of the experiment is much greater than is the case when the diet on the day preceding is essentially that of the experiment and when at 7 o'clock each morning the body may be said to be in the same equilibrium with regard to material.[2]

METABOLISM EXPERIMENT No. 102.

Subject, W. O. A., April 17–18, 1903. Age, 59 years; height, 168 cm.; weight without clothing, 84.8 kilos.

From these data it is seen that the subject was distinctly fat. He entered the respiration chamber on the evening of April 16, 1903, went to bed at the usual time, and rested comfortably until morning. He reported that during the night he slept fairly well, but not so soundly as usual. He woke several

[1] Carpenter and Benedict, Journ. Biol. Chem., 1909, 6, p. 271.
[2] Benedict, Carnegie Institution of Washington Publication No. 77, p. 85, 1907.

times and turned over, and rose at 7 o'clock on the morning of April 17. Five 6-hour periods were measured in this experiment, beginning at 1 a. m., April 17, and ending at 7 a. m., April 18. During two of these periods, the first and last, the body conditions were identical so as to afford reasonable basis for comparison.

Program and records of activity and body-temperature.—Aside from being instructed to move about as little as possible and not to make movements without notifying the observer, no prescribed program was laid down for this subject. He ate 3 meals during the course of the day, retired at the usual time (10 o'clock at night), and slept until 7 o'clock in the morning. In this experiment it was not practicable to separate the urine in the number of periods; therefore we have only the total urine for the 24 hours. No attempts were made to separate the feces, although there was a defecation inside the chamber during the experiment. A record of muscular activity as made by the observers is appended hereto.

Movements of subject from Apr. 17, 1 a. m. to Apr. 18, 7 a. m., 1903—Metabolism experiment No. 102.

April 17.	
A. M.	
$1^h 00^m$ } 7 00 }	In bed asleep.
7 00	rose, dressed, and made up bed.
7 10	at food aperture to take out clinical thermometer.
8 25	at food aperture to take out articles, ate breakfast.
9 16	defecation (?)

April 17.	
A. M.	
$10^h 10^m$	at food aperture to put in clinical thermometer, letters, and papers.
P. M.	
$1^h 30^m$	at food aperture twice to take out and put in articles, ate dinner.
2 00	at food aperture to put in and take out articles.
6 10	at food aperture to take out papers.

April 17.	
P. M.	
$6^h 26^m$	at food aperture to put in papers.
7 15	at food aperture to take out articles, ate supper.
10 00	retired.
April 17–18.	
10 00 } A. M. } $7^h 00^m$ }	in bed asleep.

To this record of muscular activity, the subject had the following notes to add:

Rose 7 a. m.
Took temperature at $7^h 15^m$ a. m.
Made up bed and made a number of weighings of bed and clothing before dressing, that is, with underclothes and slippers on. Weighed self in stockings without slippers. Considerable time was necessary to adjust the scales and arrange the several articles and weigh each lot.
Urine was passed about $7^h 30^m$ a. m.
Breakfast $8^h 15^m$ to $8^h 45^m$ a. m., consisting of cereal, crackers, milk, butter, and tea. Ate about one-half of the cereal furnished and about one-third of the crackers and sugar.
Dinner was eaten between $1^h 30^m$ and 2 p. m. About one-third of the cereal and ginger-snaps was eaten.
Ate supper at $7^h 15^m$ p. m. and retired at 10 p. m.

The body-temperature was taken with a clinical thermometer in the rectum, as follows: April 17, 7 a. m., 98.1° F.; April 18, 7 a. m., 98.1° F.

FOOD.

The total amounts of food eaten, together with estimated amounts of nutrients and energy, are given in table 9 herewith. The diet furnished about 14.3 grams of nitrogen and about 1900 calories of energy.

TABLE 9.—*Weight, total nutrients, and energy of food—Metabolism experiment No. 102.*

[Amounts consumed by the subject.]

Kind of food.	Weight.	Protein.	Fat.	Carbo-hydrates.	Energy.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Cals.*
Apples	149.8	0.22	0.4	20.3	80.9
Beef	100.0	33.28	2.8	....	217.7
Butter	15.9	0.18	13.7	....	125.7
Crackers (soda)	47.2	4.63	4.3	34.5	211.7
Breakfast cereal	100.0	15.28	1.4	71.5	400.2
Ginger-snaps	9.5	0.49	0.9	7.2	40.3
Milk	886.1	33.05	39.1	46.4	745.2
Sugar	25.0	...	....	25.0	99.0
Tea	395.5	0.40	....	1.3	5.0
Total	1729.0	87.53	62.6	206.2	1925.7

URINE.

From 7 a. m., April 17, to 7 a. m., April 18, the urine was carefully collected. There were 695.9 grams of urine, with a specific gravity of 1.030, and containing, by analysis, 10.80 grams of nitrogen, and by combustion, 90 calories of energy. No analyses of feces were made.

ELIMINATION OF WATER-VAPOR AND CARBON DIOXIDE.

The water vaporized from the lungs and skin, the carbon dioxide exhaled, and the oxygen absorbed, are recorded in table 10.

The water vaporized in the chamber remained very constant from period to period, being a little over 200 grams. A knowledge of the water thus vaporized is of great value in estimating the amount of energy required to vaporize this water, and supplies one of the factors for the calculation of the total heat production. Here, as in experiment 101, no attempt has been made to designate whether the water vaporized was from the bed clothing, skin, or lungs of the subject, or from articles used in the chamber, the important point being that a certain amount of water was vaporized and heat was required to vaporize this water. The data regarding the residual amount of water-vapor permit the computation of the relative humidity.

The amount of carbon dioxide remaining inside the respiration chamber at the end of each period is recorded, as well as the total carbon dioxide eliminated. There are the usual slight fluctuations in these residual amounts. The total carbon-dioxide production is not far from 200 grams per period, although during sleeping hours it dropped to about 140 grams. The excessive elimination from 7 a. m. to 1 p. m. may be accounted for by the extra work involved in the weighings made by the subject immediately after getting up in the morning.

OXYGEN CONSUMED.

This experiment was one of the first metabolism experiments in which the determination of oxygen was reasonably satisfactory. Subsequent experiments have greatly improved the technique and accuracy. The method of computing the oxygen has been explained in detail elsewhere.[1] The total amount of oxygen consumed in each period is given in the sixth column of table 10. The largest amount is during the period from 7 a. m. to 1 p. m., corresponding to the increased muscular activity involved in the weighings. During the remaining periods, the amounts are more constant for the respective conditions of awake and sleeping.

TABLE 10.—*Water vaporized, carbon dioxide exhaled, and oxygen consumed—Metabolism experiment No. 102.*

Date and period.	Water.		Carbon dioxide.		Oxygen.	
	Weight in chamber at end of period.	Total weight vaporized.	Weight in chamber at end of period.	Total weight exhaled by subject.	Volume in chamber at end of period.	Total weight consumed by subject.
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Liters.*	*Grams.*
Apr. 16-17, 1903:						
7 p.m. to 1 a.m.	51.8	....	42.1	....	920.7	....
1 a.m. 7 a.m.	49.9	208.8	37.0	139.8	923.8	128.4
Apr. 17-18, 1903:						
7 a.m. to 1 p.m.	49.8	227.1	43.7	248.5	902.2	217.8
1 p.m. 7 p.m.	46.4	208.9	44.4	209.0	910.4	177.8
7 p.m. 1 a.m.	49.2	208.9	38.4	193.9	910.9	165.5
1 a.m. 7 a.m.	50.0	209.6	35.7	142.1	905.4	128.1
Total, 7 a.m. to 7 a.m.	....	854.5	....	793.5	....	688.7

HEAT ELIMINATION AND PRODUCTION.

Of all the subjects formerly used in this respiration apparatus, none had been of the same type of build as this subject, who presented a distinctly large proportion of adipose tissue; hence the heat production of this subject is of unusual interest. The electrical-resistance thermometer was not at that time in use to determine the body-temperatures, and therefore we have only the records at the beginning and end of the last 24 hours, which indicate that there was no change in body-temperature from 7 a. m. on April 17 to 7 a. m. April 18. Consequently, the heat production can not be computed for the shorter periods. The total heat elimination, however, has been computed for these periods, and is given in table 11. It should be noted that the correction for the heat in bed and bedding is made during the first period in the morning and during the period from 7 p. m. to 1 a. m. As with the carbon-dioxide and water eliminations, the total heat elimination is largest from 7 a. m. to 1 p. m., due to the excessive muscular exercise of this period, and lowest during the

[1] Atwater and Benedict, Carnegie Institution of Washington Publication No. 42; Benedict, *ibid.*, Publication No. 77.

sleeping-hours from 1 a. m. to 7 a. m. Considering the 24 hours from 7 a. m. to 7 a. m., the heat elimination was practically equal to the heat production, as there was but a slight minus correction of a fraction over 2 calories for the change in body weight.[1]

TABLE 11.—*Summary of calorimetric measurements and total heat eliminated—Metabolism experiment No. 102.*

Date and period.	(*a*) Heat measured in terms C_{20}.	(*b*) Heat used in vaporization of water.	(*c*) Sum of heat corrections.	(*d*) Total heat eliminated. (*a*+*b*+*c*)
	Calories.	*Calories.*	*Calories.*	*Calories.*
April 17, 1908: 1 a.m. to 7 a.m.	310.4	122.4	− 4.5	428.3
April 17-18, 1908:				
7 a.m. to 1 p.m.	622.1	133.1	− 37.7	717.5
1 p.m. 7 p.m.	490.0	122.4	− .4	612.0
7 p.m. 1 a.m.	407.7	122.4	+ 31.1	561.2
1 a.m. 7 a.m.	321.6	122.8	+ .8	445.2
Total, 7 a.m. to 7 a.m.	1841.4	500.7	[1]− 8.5	[2]2333.6

[1] Includes correction for change of body weight from 7 a. m. to 7 a. m.
[2] Total heat production.

BALANCE OF MATTER AND ENERGY.

Method of computation.—In accordance with the plan used successfully in a previous report, it has been deemed advisable to present results of experiments of this nature, first, as a study of katabolism, and, second, as a study of the extent to which food ingested met the demands upon the body. This method of presentation has specific value in that the errors incidental to the sampling and analysis of foods do not enter into the computations of the total katabolism. Consequently, this experiment will be first treated from the standpoint of the katabolism itself.

Material katabolized in the body.—The computation of the total katabolism is rendered relatively accurate by the numerous determinations made in connection with these experiments, for from the analyses of the urine and the gaseous exchange, it is possible for us to determine the total output of nitrogen, carbon, hydrogen, and oxygen. In the calculation of the katabolism, the only income which is considered is the oxygen absorbed from the air. Furthermore, preformed water which is taken with the food and drink does not enter into the calculation. The method of computing the results has been explained in detail in several publications.[2] The data and the materials katabolized are given in table 12.

[1] For a complete discussion of the method of computing the amount of heat residual in the body see Carnegie Institution of Washington Publication No. 77, 1907, p. 46.
[2] Atwater and Benedict, Carnegie Institution of Washington Publication No. 42, 1905; Benedict, *ibid.*, Publication No. 77, 1907; Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. 175, 1907.

TABLE 12.—*Elements and materials katabolized in body, Apr. 17-18, 1903, 7 a. m. to 7 a. m.—Metabolism experiment No. 102.*

	Grams.		Grams.
Nitrogen	10.8	Water[1]	583.8
Carbon	224.8	Protein	64.8
Hydrogen	97.8	Fat	117.8
Oxygen	658.8	Carbohydrates	226.8

[1] Water of urine not included.

An interesting comparison of the energy derived from katabolized body-material with the total heat production shows a most satisfactory agreement between the direct and the indirect calorimetry. (See table 13.)

TABLE 13.—*Comparison of energy as computed from body-material katabolized with heat production as measured, Apr. 17-18, 1903, 7 a. m. to 7 a. m.—Metabolism experiment No. 102.*

	Cals.
(*a*) Energy of body protein katabolized	366
(*b*) Potential energy of urine	90
(*c*) Net energy (*a*—*b*)	276
(*d*) Energy of body fat katabolized	1124
(*e*) Energy of body glycogen katabolized	948
(*f*) Total energy computed from katabolized material (*c*+*d*+*e*)	2348
(*g*) Total heat production as measured	2334
Heat production computed greater than heat production measured:	
(*h*) Amount (*f*—*g*)	+14
	Per cent.
(*i*) Proportion (*h*÷*g*)	+0.6

Material absorbed from food.—Having considered the katabolism of this subject, it is now proper to inquire as to how far the diet ingested during this experiment sufficed for maintenance. From the assumed composition of food materials eaten, the amounts of protein, fats, and carbohydrates absorbed from the food and the energy of each have been calculated and placed in table 14. In these calculations it has been necessary to assume the percentage composition of food material. This has been done after reference to the average of a large number of analyses of food materials of a like nature previously used in this laboratory. Furthermore, in the absence of a satisfactory separation of feces, it is necessary to assume the coefficients of digestibility for the different nutrients. It is seen from the figures presented in the table that the energy supplied by the food is 1859 calories.

TABLE 14.—*Amounts of protein, fat, and glycogen absorbed*[1] *from food, and energy of each,*[2] *Apr. 17-18, 7 a. m. to 7 a. m.—Metabolism experiment No. 102.*

Material.	Amount.	Energy.
	Grams.	*Calories.*
Protein	79.2	448
Fat	59.6	569
Glycogen	201.0	842
Total	....	1859

[1] Assuming as coefficients of digestibility for protein, 90.5 per cent; for fat, 95.2 per cent; for carbohydrates, 97.5 per cent. (United States Department of Agriculture, Office of Exp. Stas. Bul. 175, p. 130.) The results are in terms of body-material.

[2] Factors for heat of combustion per gram of protein, 5.65 calories; of fat, 9.54 calories; of glycogen, 4.19 calories.

Balance of intake and output of nutrients and energy.—Comparing the nutrients and the energy absorbed from the food with the material katabolized shows many interesting points. The results have been calculated and placed in table 15. It is there seen that the diet furnished a somewhat liberal amount of protein, inasmuch as some 14 grams were stored during the 24 hours. There was a loss of 58 grams of body-fat and a loss of 25 grams of glycogen; consequently it is seen that there was a large deficiency in energy amounting to 565 calories. It is clear, therefore, that this diet did not suffice for maintaining this subject in energy equilibrium.

TABLE 15.—*Balance of intake and output of nutrients and energy, Apr. 17-18, 1903, 7 a.m. to 7 a.m.—Metabolism experiment No. 102.*

Body-protein:	*Grams.*	Body-carbohydrate:	*Grams.*
(*a*) Absorbed from food[1]	79.2	(*g*) Absorbed from food[3]	201.0
(*b*) Katabolized	64.8	(*h*) Katabolized	226.8
(*c*) Gain to body (*a*−*b*)	+ 14.4	(*i*) Loss to body (*g*−*h*)	− 25.8
Body-fat:		Energy:	*Cals.*
(*d*) Absorbed from food[2]	59.6	(*j*) Computed from nutrients absorbed[4]	1859
(*e*) Katabolized	117.8	(*k*) Heat production plus potential energy of urine	2424
(*f*) Loss to body (*d*−*e*)	− 58.2	(*l*) Loss to body (*j*−*k*)	− 565

[1] Calculated by means of average coefficient of digestibility of protein, 90.5 per cent.
[2] Calculated by means of average coefficient of digestibility of fat, 95.2 per cent.
[3] Calculated by means of average coefficient of digestibility of carbohydrates, 97.5 per cent.
[4] From results in columns (a) (d) and (g) in terms of body-material, factors 5.65, 9.54, and 4.19 calories respectively.

COMPARISON OF FACTORS OF METABOLISM.

The relations existing between the oxygen consumption, carbon-dioxide production, and heat elimination are calculated and presented in table 16. As an index of the material burned in the body, the respiratory quotient is of great value. Here it is found to fluctuate between 0.80 and 0.85, the largest quotients appearing during the day, when the carbohydrates were ingested, and the smaller quotients during the night, when the combustion of carbohydrates is at the minimum.

TABLE 16.—*Oxygen and carbon-dioxide thermal quotients and respiratory quotients—Metabolism experiment No. 102.*

Date and period.	(*a*) Total heat eliminated.	(*b*) Oxygen consumed.	(*c*) Oxygen thermal quotient (100*b*÷*a*)	(*d*) Carbon dioxide eliminated.	(*e*) Carbon-dioxide thermal quotient (100*d*÷*a*)	(*f*) Volume of carbon dioxide eliminated. (*d*×0.509)	(*g*) Volume of oxygen consumed. (*b*×0.7)	(*h*) Respiratory quotient (*f*÷*g*)
	Cals.	*Grams.*		*Grams.*		*Liters.*	*Liters.*	
Apr. 16-17, 1903. 1 a.m. to 7 a.m.	428.3	126.4	29.5	139.8	32.6	71.2	88.5	0.80
Apr. 17-18, 1903.								
7 a.m. to 1 p.m.	717.5	217.3	30.3	248.5	34.6	126.5	152.1	.83
1 p.m. 7 p.m.	612.0	177.8	29.1	209.0	34.2	106.4	124.5	.85
7 p.m. 1 a.m.	561.2	165.5	29.5	193.9	34.6	98.7	115.8	.85
1 a.m. 7 a.m.	445.2	128.1	28.8	142.1	31.9	72.3	89.6	.81
Total, 7 a.m. to 7 a.m.	[1]2333.6	688.7	29.5	793.5	34.0	403.9	482.0	.84

[1] Heat production.

METABOLISM EXPERIMENT No. 103.

Subject, B. F. D., November 23, 1903. Age, 22 years; height, 170 cm.; weight without clothing, 68.4 kilos.

In connection with a large number of experiments, it was found that the body-position seemed at times to exert a marked influence upon metabolism, and hence it appeared desirable to get some definite data regarding the metabolism under the various conditions of lying, sitting, and standing. This experiment was designed with the purpose of studying this problem, but the research was not carried farther at that time, owing to the press of other work.

The subject was a young man, a student in Wesleyan University, and was also the subject of a number of subsequent experiments which have been published elsewhere.[1] He entered the respiration chamber in the early morning wearing only a moderately heavy woolen union suit and a pair of thick-soled shoes. The object of making the experiment with the union suit was to note the effect on heat production of varying amounts of clothing, but this study was not carried farther.

During the whole experiment the temperature inside the respiration chamber remained not far from 20° C., and although the subject wore only this heavy union suit, weighing 580 grams, he did not complain of any discomfort as a result of the temperature. During the time the subject was required to lie in bed without clothing over him, *i. e.*, from $10^h\,29^m$ a. m. to $12^h\,37^m$ p. m., he was not asleep, but was lying quietly. From $12^h\,37^m$ to $3^h\,02^m\,32^s$ p. m. he was sitting quietly, and from $3^h\,02^m\,32^s$ to $5^h\,33^m$ p. m. he was standing. During the experiment he took his temperature with a clinical thermometer in the mouth, and the records are as follows: $10^h\,20^m$ a. m., 98.4° F.; $12^h\,30^m$ p. m., 98.6° F.; 3 p. m., 98.3° F.; $5^h\,33^m$ p. m., 98.8° F.

Inasmuch as the subject held the stipulated positions without any variations during the whole period, there were no minor muscular movements to be recorded as incidental to the experiment. Determinations were made of the water vaporized, carbon-dioxide elimination, oxygen consumption, and heat elimination.

TABLE 17.—*Water vaporized—Metabolism experiment No. 103.*

Date and period.	(a) Weight in chamber at end of period.	(b) Gain (+) or loss (−) from preceding period.	(c) Weight absorbed from outcoming air.	(d) Corrected weight vaporized. (b+c)
Nov. 23, 1903:	*Grams.*	*Grams.*	*Grams.*	*Grams.*
$10^h\,29^m$ a.m.	48.94	....	....	....
$10^h\,29^m$ a.m. to $12^h\,37^m$ p.m.	40.49	− 8.45	105.94	97.5
$12^h\,37^m$ p.m. to $3^h\,02^m\,32^s$ p.m.	36.96	− 3.53	101.64	98.1
$3^h\,02^m\,32^s$ p.m. to $5^h\,33^m$ p.m.	36.19	− 0.77	114.30	113.5

[1] Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. 175, 1907; Benedict and Carpenter, *ibid.*, Bul. 208, 1909; Benedict, Carnegie Institution of Washington Publication No. 77, 1907.

WATER VAPORIZED AND CARBON DIOXIDE ELIMINATED.

The amounts of water vaporized inside the chamber are given in table 17. No large variations are noted in the amounts of water remaining in the chamber, and in this experiment, as in most of the others, the humidity remained reasonably constant. The quantities of carbon dioxide eliminated during the experiment are shown in table 18. Of special note in this table is the enormous increase in the amount of carbon-dioxide residual in the chamber at the end of the successive periods. This increase is altogether out of proportion to the normal content in experiments of this kind. At first sight one might reasonably think that the very large amount of carbon-dioxide residual in the chamber in the afternoon, for example, might materially influence the gaseous exchange. Fortunately there was a subsequent experiment made with this subject, in which the influence of excessive amounts of carbon dioxide was carefully studied.[1] From that experiment it seems highly probable that the presence of a large amount of carbon dioxide does not influence in any measurable amounts the excretion of carbon dioxide, and hence the quantities in the last column of the table may be taken as normal results for the periods. The explanation of this large increase in the residual amount of carbon dioxide can in all probability be found in the fact that the soda-lime in the purifying vessels had become exhausted and had not been replaced by fresh material in other vessels. An examination of the nature of the ventilation system of an apparatus of this type shows, however, that any carbon dioxide escaping absorption is not lost, but is returned to the chamber, there to be absorbed in a subsequent period or accumulated, as was the case in this experiment.

TABLE 18.—*Record of carbon dioxide—Metabolism experiment No. 103.*

Date and period.	(*a*) Weight in chamber at end of period.	(*b*) Gain (+) or loss (−) from preceding period.	(*c*) Weight absorbed from outcoming air.	(*d*) Weight exhaled by subject. (*b*+*c*)
Nov. 23, 1903:	*Grams.*	*Grams.*	*Grams.*	*Grams.*
10h 29m a.m.	69.72	....	....	....
10h 29m a.m. to 12h 37m p.m.	97.76	+ 28.04	42.67	70.7
12h 37m p.m. to 3h 02m 32s p.m.	144.98	+ 47.22	18.78	66.0
3h 02m 32s p.m. to 5h 33m p.m.	186.83	+ 41.85	43.19	85.0

MEASUREMENTS OF OXYGEN AND HEAT.

The data for the oxygen consumption are given in table 19. The accumulation of a large amount of carbon dioxide in the chamber naturally affected in a marked manner the residual amount of oxygen, and hence made necessary rather large corrections. While the possibility of error is somewhat greater with oxygen than with carbon dioxide, we have every reason to believe that

[1] The results of this experiment, which is, perhaps, the most complete of any made on this subject, are reported by Benedict and Milner, U. S. Dept. Agr., Office Exp. Stas. Bul. 175, 1907, p. 94.

the measurements for oxygen as here determined are as accurate as those ordinarily determined for residual amounts.

The calorimeter measurements obtained during this experiment are given in table 20. They require no special comment other than the statement that the periods were not of equal length, and hence the figures in the last column can not be compared with each other on this basis without recalculation.

TABLE 19.—*Record of oxygen—Metabolism experiment No. 103.*

Date and period.	(a) Volume in chamber at end of period.	Gain (+) or loss (—) from preceding period. (b) Volume.	(c) Weight. (b+0.7)	(d) Weight admitted to chamber.	(e) Weight consumed by subject. (d—c)
Nov. 23, 1903:	*Liters.*	*Liters.*	*Grams.*	*Grams.*	*Grams.*
10h 29m a.m.	952.40	....	....	....	....
10h 29m a.m. to 12h 37m p.m.	934.79	—17.61	—25.16	32.28	57.4
12h 37m p.m. to 3h 02m 32s p.m.	900.59	—34.20	—48.86	12.88	61.7
3h 02m 32s p.m. to 5h 33m p.m.	871.48	—29.11	—41.59	37.15	78.7

TABLE 20.—*Summary of calorimetric measurements and total heat production—Metabolism experiment No. 103.*

Date and period.	Heat measured in terms C_{20}.	Heat used in vaporization of water.	Sum of heat corrections.	Total heat production.
Nov. 23, 1903:	*Calories.*	*Calories.*	*Calories.*	*Calories.*
10h 29m a.m. to 12h 37m p.m.	158.6	57.1	+ 2.8	218.5
12h 37m p.m. to 3h 02m 32s p.m.	190.7	57.5	— 12.1	236.1
3h 02m 32s p.m. to 5h 33m p.m.	201.4	66.5	+ 18.9	286.8

COMPARISON OF RESULTS WITH DIFFERENT ACTIVITIES.

Inasmuch as the periods were not of equal length, it is advisable in comparing the results of the katabolism during different periods to compute them on the basis of 1 hour. These calculations have been made and the results have been presented in table 21. During the period when the subject was lying down, the amount of carbon dioxide excreted amounted to 33.1 grams per hour. When he was sitting in the chair, it was somewhat less, 27.2 grams, and when standing, it was slightly above the initial lying-down value. Similar fluctuations are noted in the amounts of water vaporized and there is a similar tendency for the oxygen absorbed, although the falling off during the period of sitting is not so noticeable. The heat eliminated shows a gradual increase during the three successive periods, but when the heat production is calculated, making due allowance for changes in body-temperature and body-weight, it is found that the heat production during lying down was actually greater than during sitting, although less than during standing.

In interpreting these results, it is important to note that the values for lying down are probably slightly influenced by the digestion of the food taken

prior to this period, and hence all the values for this condition are somewhat higher than would be expected. Making this allowance it is rather striking to find that the variation between the values for lying down and for sitting is so small. For purposes of comparison, the change of position from sitting to standing is much more accurately indicated by these experiments, since the digestive processes were probably much the same during both periods and the differences in katabolism can be ascribed solely to differences in body-position. There is a noticeable increase in the total katabolism and the heat production indicates an increase of some 17 per cent during the standing period.

TABLE 21.—*Amounts per hour of carbon dioxide, water, and heat eliminated, oxygen consumed and heat produced—Metabolism experiment No. 103.*

Date and period.	Carbon dioxide eliminated.		Water vaporized.		Oxygen absorbed.		Heat eliminated.		Heat produced.	
	Total.	Amt. per hour.	Total.	Amt. per hour.	Total.	Amt. per hour.	Total.	Amt. per hour.	Total.	Amt. per hour.
Nov. 23, 1903:	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Cals.*	*Cals.*	*Cals.*	*Cals.*
Lying down— $10^h 29^m$ a.m. to $12^h 37^m$ p.m.	70.7	33.1	97.5	45.7	57.4	26.9	213.7	100.2	218.5	102.4
Sitting— $12^h 37^m$ to $3^h 02^m 32^s$ p.m....	66.0	27.2	98.1	40.4	61.7	25.5	246.8	101.8	236.1	97.2
Standing— $3^h 02^m 32^s$ to $5^h 33^m$ p.m....	85.0	33.9	113.5	45.3	78.7	31.4	272.9	108.8	286.8	114.4

METABOLISM EXPERIMENT No. 104.

Subject, B. F. D., March 3, 1904. (Same subject as in experiment No. 103.)

Two experiments of one day each, in which this subject rode the bicycle-ergometer, were made on the two days immediately preceding, and this experiment was planned for the purpose of obtaining the metabolism during rest for comparison with that during the preceding work periods. This experiment has, therefore, been partially reported in a previous publication[1] in which comparison has been made of the heat output during rest and during muscular work.

The subject entered the calorimeter chamber at about 6 a. m. and the experiment was begun at 7 a. m., at which time he was weighed in a chair suspended from the platform scale. The usual program in rest experiments was followed. Four 3-hour periods were run and the subject left the chamber at 7 p. m. Two meals were eaten, the first between 7 and 8 a. m., and the second between 1 and 2 p. m. The total food consumed consisted of milk, 1582 grams; bread, 152 grams; butter, 26 grams; meat, 257 grams; coffee, 201 grams; sugar, 30 grams; apples, 600 grams. The pulse, as counted by the subject at $7^h 25^m$ a. m., was 53. The sublingual body-temperature at 7 a. m. was 98.8° F. and at 7 p. m., 98.8° F. Urine, in two amounts of 163.8 and 636.1 grams, respectively, was voided during the experiment. The measurements of carbon dioxide, oxygen, and heat are recorded in table 44.

[1] Benedict and Carpenter, U. S. Dept. Agr., Office Exp. Stas. Bul. 208, 1909.

METABOLISM EXPERIMENT No. 105.

Subject, B. F. D., May 5–7, 1905. (Same subject as in experiment No. 103.)

In a long series of experiments on the influence of inanition on metabolism, several were more or less incomplete. One of these, experiment No. 105, was planned to continue 2 regular days of 24 hours each, but during the second night in the respiration chamber the subject became nauseated and it was necessary to remove him and interrupt the experiment. In all probability this subject suffered from the mercurial poisoning noted in connection with the respiration chamber at about this time. A few notes upon this experiment, particularly those pertaining to the appearance of toxic symptoms, have been published elsewhere.[1] Since, however, the degree of poisoning was not sufficient to cause a noticeable temperature rise and toxic symptoms were absent until near the end of the experiment, we believe that at least the first part can be considered as normal, and hence it is reported here.

Routine and record of activity.—The subject followed the usual practice and entered the calorimeter early the night before in order to have a preliminary night in the chamber before beginning the experiment proper. After entering, some time was spent in adjusting the furniture and apparatus for the contemplated 2-day experiment. The temperature equilibrium had been established so quickly that it was possible to begin the preliminary observations at 9 p. m. and from that time on the observations were made in 2-hour periods. At 11 p. m. urine was collected and the subject arranged the furniture, adjusted the bed, undressed, and retired. The diary kept by the subject showed that he slept well until 5 a. m., and then dozed until 7 a. m., when he was called. At this time the urine was collected, the furniture was arranged for the day, and the chair, man, and clothes were weighed. The body movements in this experiment were only those incidental to the process of weighing, obtaining and drinking water, collecting urine, and some minor muscular activity. At $7^h\ 24^m$ a. m. the electrical rectal thermometer was inserted. The record of the body movements is given herewith. They are of value in indicating the relative body activity from period to period.

As is seen from an inspection of these data, the subject remained fairly quiet throughout the day, for the most part sitting in his chair and reading. He retired at about the usual time, shortly after 11 p. m., but was troubled a little with nausea. It was soon found that instead of sleeping quietly, the subject was restless and at 12 o'clock he was not asleep. Nausea began again and it was necessary to remove him from the chamber at 1 a. m., May 7.

Since the experimental day was supposed to begin at 7 a. m. and the experiment was primarily a study of fasting, the removal of the subject at 1 a. m. prevented the completion of a 24-hour day for the special purpose for which

[1] Carpenter and Benedict, Am. Journ. Physiol., 1909, **24**, p. 192.

the experiment was planned. Hence, unfortunately, the urine collected during the partial day was not analyzed and the data for the metabolism are therefore incomplete. The determination of the gaseous exchange and the heat measurements were, however, made with the customary regularity, and it is believed with the usual accuracy.

Movements of subject from May 5, 9 p.m., to May 7, $1^h 02^m$ p.m., 1905—Metabolism experiment No. 105.

	May 5.
P. M.	
$9^h 18^m$	stood, adjusted table, sat, read.
11 04	passed urine, adjusted table, undressed, retired.
11 12	drank water.
	May 6.
A. M.	
$7^h 01^m$	rose, passed urine.
7 05	dressed, adjusted chair, weighed self and clothes.
7 08	telephoned, adjusted table.
7 14	food aperture, drank water.
7 16	sat, wrote.
7 20	telephoned.
7 24	stood, inserted rectal thermometer.
7 26	sat, wrote.
7 39	read.
8 50	drank water.
9 14	telephoned.
9 22	read.
10 09	stood, adjusted rectal thermometer.
10 13	stood, food aperture.
10 15	sat.
10 20	wrote, drank water.
10 21	stood, food aperture.
10 23	read.
11 15	drank water.
11 18	telephoned.

	May 6.
A. M.	
$11^h 19^m$	stood, food aperture.
11 38	read.
P. M.	
$12^h 11^m$	wrote.
12 14	read.
12 29	drank water.
12 30	wrote.
12 32	read.
1 00	passed urine.
1 02	telephoned, food aperture.
1 08	sat.
1 25	stood, food aperture.
1 27	sat, wrote.
1 29	read.
1 37	stood, adjusted bed.
1 40	lay on bed.
2 00	asleep.
3 01	awoke.
3 06	stood.
3 08	folded up bed.
3 10	sat and wrote.
3 11	stood.
3 12	passed urine.
3 14	sat, drank water.
3 18	read.
4 00	wrote.
5 06	wrote.
5 22	read.
5 33	stood, food aperture.
5 36	read.
5 46	drank water.
6 18	telephoned.
6 24	read.
6 42	telephoned.

	May 6.
P. M.	
$7^h 01^m$	stood, passed urine, food aperture.
7 03	sat, drank water.
7 04	wrote.
7 06	read.
7 28	read, telephoned.
7 50	adjusted table and bed.
7 52	lay on bed.
9 02	asleep.
10 06	rose on elbow.
10 10	nausea.
10 40	telephoned.
10 52	sat up on bed.
11 02	telephoned, sat up, nausea, passed urine, telephoned.
11 08	nausea.
11 10	telephoned.
11 12	stood, food aperture.
11 14	cleaned floor.
11 16	food aperture, retired.
11 20	telephoned.
11 24	lay down.
11 46	restless.
11 54	quiet.
	May 7.
A. M.	
$12^h 22^m$	awoke.
12 26	telephoned.
12 30	food aperture.
12 32	lay down.
12 52	telephoned.
1 02	left calorimeter.

Drinking-water, pulse, and body-temperature.—Drinking-water was taken freely, the first amount, 100 c. c., being taken at $11^h 12^m$ p. m. of May 5. The following record gives the amounts taken on May 6:

$7^h 15^m$ a. m.	200 c. c.	$12^h 29^m$ p. m.	150 c. c.
8 50	200	3 15	150
10 20	100	5 45	100
11 15	150	7 03	50

The pulse-rate was taken by the subject himself and recorded in the diary. No respirations were recorded. The records of the pulse-rate as reported by the subject are as follows:

May 5	$9^h 40^m$	p.m.	61	May 6	$3^h 16^m$	p.m.	51
May 6	7 19	a.m.	59		3 56		65
	9 45		51		4 45		65
	10 51		56		6 49		71
	12 10	p.m.	61		7 52		68
	1 10		53				

The body-temperature was taken from $7^h 30^m$ a. m. until 9 p. m., May 6, by means of the electrical rectal thermometer, and was as follows:

			°C.				°C.
May 6	$7^h 30^m$	a.m.	36.68	May 6	$3^h 00^m$	p.m.	36.57
	9 00		36.62		5 00		36.76
	11 00		36.66		7 00		36.93
	1 00	p.m.	36.49		9 00		37.11

No food was taken during the whole experiment.

Metabolism and heat production.—The results of the gaseous exchange, the heat elimination, and, in so far as the data permit, the heat production are given in table 44. As the results obtained in the experiment reported are compared with results obtained in experiments of a similar nature, it is necessary here only to call attention to the fact that the metabolism as indicated by the gaseous exchange and heat production was fairly regular for particular conditions throughout the experiment. The noticeable inequalities appeared only during those periods when the subject was more or less asleep, or when he was more or less muscularly active. Of special significance is the noticeable increase in the carbon-dioxide elimination and oxygen consumption during the evening of May 6 when the subject was disturbed by nausea. The indications are that the last few periods of this experiment can not be considered as normal, and hence in the averages the results for these periods will not be included.

METABOLISM EXPERIMENT No. 106.

Subject, B. F. D., May 31, 1905. (Same subject as in experiment No. 103.)

The subject entered the chamber between 1 and 2 p. m. for a short experiment of only $2^h 30^m$. This subject had been sick in a previous experiment and a series of experiments was begun to ascertain if he could remain in the calorimeter over night without becoming ill. At that time the indisposition mentioned was attributed to no especial cause, as evidence pointing towards mercurial poisoning had not then accumulated. No body-temperatures were taken, nor were pulse-rates recorded during this experiment, as it was practically preliminary to the series.

The subject experienced no difficulty during this period, so he was removed and a longer experiment planned for the near future. The results of the metabolism for this one period are recorded in table 44.

METABOLISM EXPERIMENT No. 107.

Subject, B. F. D., June 2, 1905. (Same subject as in experiment No. 103.)

This experiment was a continuation of the series made with this subject to ascertain whether he would experience further toxic symptoms on remaining in the calorimeter for gradually increasing periods of time. At about 1 o'clock the subject ate dinner, consisting of fish, mashed potatoes, lettuce with vinegar and sugar, bread and butter, and pudding with sugar sauce. After dinner he entered the calorimeter, was weighed at $1^h\ 52^m$ p. m. and then sat quietly until the beginning of the experiment at $2^h\ 44^m$ p. m. At the beginning of the first period he went to the food aperture once and then sat down and read. At the beginning of the second period ($4^h\ 45^m$ p. m.) he rose from his chair, went to the food aperture, and opened it twice. At $5^h\ 40^m$ p. m. the subject rose from his chair, went to the food aperture, took out the material for his supper, and then sat down and began eating. Soon afterwards he stood up again and opened the food aperture. At $6^h\ 10^m$ p. m. he finished eating supper, and then passed 160 grams of urine. At the beginning of the third period ($6^h\ 45^m$ p. m.), he opened the food aperture twice. The experiment was finished at $8^h\ 45^m$ p. m. The subject reported that he was rather sleepy at first, but became more awake at 3 o'clock. No unfavorable symptoms were noticed.

The subject's supper consisted of 483 grams of strawberries, 235 grams of sandwich, 81 grams of sugar, and 466 grams of milk. The subject recorded his own pulse-rate, the results being as follows: $2^h\ 45^m$ p. m., 65; $5^h\ 20^m$ p. m., 46; $5^h\ 52^m$ p. m., 45; $7^h\ 05^m$ p. m., 61; $8^h\ 32^m$ p. m., 65. The sublingual temperatures were: at $2^h\ 45^m$ p. m., 97.9° F.; $4^h\ 45^m$ p. m., 98.0° F.; $6^h\ 45^m$ p. m., 98.0° F.; $8^h\ 45^m$ p. m., 98.0° F. The results obtained from the measurements of the three 2-hour periods are given in table 44.

METABOLISM EXPERIMENT No. 108.

Subject, B. F. D., June 3, 1905. (Same subject as in experiment No. 103.)

This experiment was a continuation of the series with B. F. D. to determine the nature of a toxicity which subsequently appeared to be due to mercurial poisoning from the air in the respiration chamber entering from the ventilating system.

Breakfast consisted of 3 biscuits, fried potatoes, and about 350 c. c. of milk. The subject entered the chamber and was weighed at $10^h\ 50^m$ a. m. and the first period began at $12^h\ 45^m$ p. m. Immediately afterwards the subject rose from his chair, went to the food aperture and sat down again. At $1^h\ 50^m$ p. m. he went to the food aperture twice and then commenced eating. While eating, he rose 3 times and stood for a few minutes, then sat down, and shortly afterwards again rose and took milk from the food aperture. His lunch consisted of 114 grams of sandwich, 75 grams of canned baked beans, 214 grams of

strawberries, 131 grams of apples, 35 grams of sugar, and 464 grams of milk. At $2^h 04^m$ p. m., urine was passed. At $2^h 16^m$ p. m., he ate an apple. At $2^h 45^m$ p. m., he rose from his chair, opened the food aperture 4 times, and then slept on the bed until $4^h 10^m$ p. m., when he awoke and, without rising, read until $4^h 45^m$ p. m. He then rose, went to the food aperture, removed the thermometer, sat down in the chair, took his temperature, and then went to the food aperture and replaced the thermometer. At $5^h 20^m$ p. m., he drank a portion of the milk from his lunch. At $6^h 24^m$ p. m., he went to the food aperture. At $6^h 45^m$ p. m. the subject again went to the food aperture to get the thermometer, and, after taking his temperature, he replaced the thermometer and passed urine. Then the subject stood up for a few minutes. At $7^h 06^m$ p. m. he again went to the food aperture and took out his supper. At $7^h 16^m$ p. m. the subject went to the food aperture again to get milk and then commenced eating. The supper consisted of 192 grams of oranges, 243 grams of strawberries, 121 grams of sandwich, 37 grams of sugar, and 233 grams of milk. The subject finished eating at $7^h 26^m$ p. m. At 8 p. m. he stood up and remained in this position until $8^h 30^m$ p. m. when he again sat down. At $8^h 45^m$ p. m. he went to the food aperture and made the temperature observation. At $10^h 45^m$ p. m. he again went to the food aperture, removed the thermometer, took his temperature, and replaced the thermometer, and at $10^h 52^m$ p. m. began to undress. At 11 o'clock he passed urine, drank milk, and arranged the bed. The records show that at 12 o'clock he was asleep. At $12^h 52^m$ a. m. he awoke and commenced to cough and continued awake and coughing at intervals until $1^h 42^m$ a. m., when he was taken out of the chamber. The total amount of urine passed was 682 grams. The subject said in his notes that he felt normal all day, although he coughed occasionally. Soon after he went to bed he began to cough and was unable to sleep.

The pulse-rate as recorded by the subject was as follows: $11^h 30^m$ a. m., 64; $1^h 30^m$ p. m., 52; $2^h 30^m$ p. m., 57; $4^h 54^m$ p. m., 62; $7^h 10^m$ p. m., 59; $9^h 25^m$ p. m., 56. The sublingual temperatures were as follows: $12^h 45^m$ p. m., 97.9° F.; $2^h 45^m$ p. m., 98.0° F.; $4^h 45^m$ p. m., 97.9° F.; $6^h 45^m$ p. m., 97.8° F.; $8^h 45^m$ p. m., 97.8° F. The results of the metabolism for the seven periods, from $12^h 45^m$ p. m. to $1^h 42^m$ a. m., are given in table 44.

METABOLISM EXPERIMENT No. 109.

Subject, J. C. W., March 29, 1904. Age, 26 years; height, 178 cm.; weight without clothing, 75.0 kilos.

This subject (a student) had been used in a number of experiments which had been made to study the influence of excessive exercise on metabolism and the periods here reported were preliminary to another experiment which was planned to study the influence of muscular work with this subject. Inasmuch as during the forenoon he found the diet disagreed with him and was compelled therefore to give up the work experiment, no further data could be accumulated.

For the period from 1 a. m. to 7 a. m., when he was sound asleep inside the respiration chamber, the results present, we believe, a true picture of metabolism during sleep with this man, and hence they are here reported.

The subject upon the day preceding had been subsisting upon a diet containing a large proportion of carbohydrate. He entered the respiration chamber the evening before, and retired at 11 o'clock, the usual time. The regular observations began at 1 a. m. and continued until 7 a. m. The measurements were made in two periods of 3 hours each, *i. e.,* from 1 a. m. to 4 a. m. and from 4 a. m. to 7 a. m. During the whole experiment the subject was in bed covered with a blanket.

The metabolism during this experiment is indicated in table 44, which summarizes the carbon dioxide exhaled, the oxygen absorbed, the water vaporized, and the heat elimination during these periods, together with the respiratory quotient. Fortunately, for purposes of comparison, the katabolism of this particular subject is very well known, as it had been studied in a number of previous experiments. Unfortunately, we have reason to believe (although, as the subject did not wear the rectal thermometer, we can not be absolutely certain) that his body-temperature was somewhat above normal during the night. During the following forenoon the temperature as registered on the clinical thermometer was 101.0° F. Under these circumstances[1] we believe the metabolism during this night to have been somewhat above the normal for this subject. An inspection of the data of other experiments made with him show that this was the case. The pulse-rate was not recorded.

METABOLISM EXPERIMENT No. 110.

Subject, J. T. H., February 20, 1905. Age, 20 years; height, 170 cm.; weight without clothing, 56.0 kilos.

The experiment was originally planned as part of a series to study the influence of mental work on metabolism, but unfortunately the control experiment was not made and the results of this experiment were therefore not included in the publication of that series. The subject (a student) occupied the calorimeter chamber while taking a regular college examination in the subject of philosophy and reported himself as comfortable during the experiment. Dinner was eaten at the usual time (about 1 p. m.) and consisted of a small amount of roast beef, mashed potatoes with gravy, a slice of whole-wheat bread, and a piece of apple pie, and a little later the subject entered the chamber. He was weighed at $1^h\ 12^m$ p. m.

During the experiment the sublingual body-temperature was taken with a clinical thermometer, being 98.4° F. at the beginning and 98.1° F. at the end. The pulse as counted by the subject was 72 at 3 p. m. and 66 at $4^h\ 15^m$ p. m. The metabolism is given in table 44.

[1] Carpenter and Benedict, Am. Journ. Physiol., 1909, **24**, p. 187.

METABOLISM EXPERIMENT No. 111.

Subject, C. F. B., January 18, 1905. Age, 16 years 7 months; height, 170 cm.; weight without clothing, 62.2 kilos.

This experiment was the first of a series begun to study the normal metabolism of men of different ages resting quietly during varying periods of the day. No attempt was made to eliminate the effect of the ingestion of food and hence, in nearly all the experiments, food was taken prior to or during the experiment.

The subject was an assistant in the laboratory and was therefore familiar with the routine of the experiments. He entered the respiration chamber in the forenoon and the experiment began at $1^h\ 40^m$ p. m. No food was taken after the breakfast in the early morning. During the greater portion of the time the subject remained sitting quietly in an arm-chair reading, although he left the arm-chair twice, went to the food aperture, and took out a bottle of water. The experiment ended at $5^h\ 40^m$ p. m. During the experiment the subject drank 218 c. c. of water and passed 647 grams of urine. Analyses of the urine were not made and no observations were made of the pulse and body-temperature. As this was the first experiment with this subject and the first of this type in the calorimeter, but one 4-hour period was made. The results of the metabolism are given in table 44.

METABOLISM EXPERIMENT No. 112.

Subject, T. M. C., February 13, 1905. Age, 26 years 5 months; height, 166 cm.; weight without clothing, 50.7 kilos.

The subject (a chemist) entered the respiration chamber shortly after dinner, which consisted of 3 boiled eggs, 2 rolls and butter, ½ pint of cream, and 1 cup of cocoa, with 2 teaspoonfuls of sugar. The subject entered the chamber and was weighed at $1^h\ 15^m$ p. m. He felt very warm, owing to the hot cocoa, and so removed his coat. The experiment proper began at $2^h\ 06^m$ p. m. and continued until $6^h\ 06^m$ p. m., subdivided into two 2-hour periods. At $4^h\ 30^m$ p. m. the subject rose, opened the food aperture, and sat down again. Although never having served as a subject in the respiration chamber before, he was perfectly familiar with the apparatus and experienced no abnormal sensations as a result of the experiment.

The pulse-rate recorded by the subject was as follows: $3^h\ 11^m$ p. m., 88; $4^h\ 00^m$ p. m., 82; $4^h\ 38^m$ p. m., 84; $5^h\ 10^m$ p. m., 80; $5^h\ 31^m$ p. m., 83. The sublingual temperature was 98.6° F. at $3^h\ 17^m$ p. m. and 98.6° F. at 6 p. m. The total metabolism as measured on this subject for two 2-hour periods is given in table 44.

METABOLISM EXPERIMENT No. 113.

Subject, T. M. C., June 7, 1905. (Same subject as in experiment No. 112.)

After a light breakfast taken about 7 a. m., and consisting of a cup of coffee with cream and sugar, one banana with cream, and one cruller, the subject entered the chamber and was weighed at $7^h\ 58^m$ a. m. The experiment proper began at $9^h\ 04^m$ a. m. Except for the usual opening and closing of the food aperture each period when receiving and replacing the clinical thermometer and twice changing the position of his chair, the subject remained seated in the chair until the beginning of the third period, when he rose, went to the food aperture, and took out his lunch. He began eating at $1^h\ 12^m$ p. m. and finished at $1^h\ 28^m$ p. m., his lunch consisting of 262 grams of oranges and sandwich (the weights were not made separately) and 454 grams of milk. The subject stated that he began to feel cool about 11 a. m., at $11^h\ 45^m$ a. m. was warm, and after lunch felt rather chilly.

The pulse-rate as recorded by the subject was as follows: $8^h\ 38^m$ a. m., 79; $9^h\ 03^m$ a. m., 79; $10^h\ 10^m$ a. m., 77; $11^h\ 05^m$ a. m., 72; $11^h\ 58^m$ a. m., 70; $12^h\ 59^m$ p. m., 66; $1^h\ 30^m$ p. m., 71; $2^h\ 05^m$ p. m., 73; $2^h\ 55^m$ p. m., 74. The body-temperatures, taken in the mouth, were at $9^h\ 04^m$ a. m., 98.4° F.; $11^h\ 04^m$ a. m., 98.4° F.; $1^h\ 04^m$ p. m., 98.1° F.; $3^h\ 04^m$ p. m., 98.3° F. The results of the metabolism for the three 2-hour periods are given in table 44.

METABOLISM EXPERIMENT No. 114.

Subject, H. C. M., April 27, 1905. Age, 27 years 6 months; height, 166 cm.; weight without clothing, 85.4 kilos.

The subject was a computer in connection with the nutrition investigations and was therefore accustomed to seeing experiments conducted with the apparatus. He entered the respiration calorimeter shortly after 8 a. m. after eating a breakfast consisting of grapefruit, lamb chops, fried potatoes, biscuit, and coffee. At $8^h\ 30^m$ a. m. he was weighed as usual in the swinging-chair inside the chamber and then settled himself comfortably in preparation for the experiment. The experiment proper began at $9^h\ 56^m$ a. m. and continued until $3^h\ 56^m$ p. m. in three 2-hour periods.

During the first two hours the subject got up once from the chair and put the thermometer into the food aperture and sat down again. Immediately after the beginning of the second period at $11^h\ 58^m$ a. m. the subject arose from his chair, went to the food aperture and took out several articles for his lunch. Between $11^h\ 58^m$ a. m. and $12^h\ 24^m$ p. m. the lunch, which consisted of 125 grams of crackers, 229 grams of bananas, and 380 c. c. of water, was eaten. Once during this period the subject stood up, moved about, and then sat down again. At the beginning of the third period the subject stood up twice, went to the food aperture, and put the uneaten food into it, then sat down. During the latter hour of the third period he was asleep for a short time. After

waking, he twice rose and sat down. At the end of each period the subject went to the food aperture to get the clinical thermometer, and after taking his temperature, opened the food aperture again and replaced the thermometer. No comments were made by the subject regarding his experience in the chamber.

The pulse-rate as recorded by the subject was as follows: at 11 a. m., 82; 12 noon, 80; 1 p. m., 80; 2 p. m., 71; 3 p. m., 75; 4 p. m., 71. The sublingual body-temperatures were as follows: at $9^h 56^m$ a. m., 98.0° F.; $11^h 56^m$ a. m., 98.0° F.; $1^h 56^m$ p. m., 97.8° F.; $3^h 56^m$ p. m., 97.6° F. The total metabolism as measured for the three 2-hour periods is given in table 44.

METABOLISM EXPERIMENT No. 115.

Subject, H. C. M., June 9, 1905. (Same subject as in experiment No. 114.)

The subject's breakfast was eaten at the usual time and consisted of veal chops, potato, rolls, and coffee. He entered the respiration chamber shortly after 8 o'clock, was weighed at $8^h 36^m$ a. m., and the experiment proper began at $9^h 53^m$ a. m. Immediately after the experiment began the subject followed the usual routine in that he rose from the chair, received the thermometer from the food aperture, took his temperature, replaced the thermometer in the food aperture, and sat down. At the beginning of the second period he repeated this operation. At $1^h 24^m$ p. m. he took his lunch from the food aperture, sat down and ate it, finishing at $1^h 46^m$ p. m. At $1^h 53^m$ p. m. he repeated the operation of taking his temperature. The experiment was finished at $3^h 53^m$ p. m. The lunch eaten consisted of 366 grams of bananas and 109 grams of crackers. He also drank 366 c. c. of water with his lunch. The subject reported at the close of the experiment that he was comfortable and had enjoyed his stay in the calorimeter.

The pulse-rate as recorded by the subject was as follows: 9 a. m., 100; 10 a. m., 88; 11 a. m., 77; 12 noon, 75; 1 p. m., 71; 2 p. m., 75; 3 p. m., 79. The sublingual body-temperatures were: at $9^h 53^m$ a. m., 98.4° F.; $11^h 53^m$ a. m., 97.8° F.; $1^h 53^m$ p. m., 98.1° F.; $3^h 53^m$ p. m., 98.1° F. The results of the metabolism for the three 2-hour periods are given in table 44.

METABOLISM EXPERIMENT No. 116.

Subject, S. C. D., April 28, 1905. Age, 31 years 2 months; height, 178 cm.; weight without clothing, 76.1 kilos.

The subject entered the chamber shortly after 8 a. m., after a breakfast consisting of 2 soft-boiled eggs, grape nuts and cream, toast and coffee. He was weighed at $8^h 15^m$ a. m., and then sat quietly until the beginning of the experiment, which was at $9^h 16^m$ a. m. At the beginning of the first period he arose from his chair and went to the food aperture, removed a bottle of water, and placed the clinical thermometer in the food aperture. At the beginning of the second period he again went to the food aperture and took out his lunch.

A little later he went to the food aperture and put in the clinical thermometer which he had been using. About 20 minutes later he again rose and went to the food aperture. From $11^h 20^m$ a. m. until $1^h 44^m$ p. m., the subject was eating intermittently. At $11^h 30^m$ a. m., he passed urine. During the third period he went to the food aperture twice in connection with the body-temperature observation. At $2^h 32^m$ p. m., he arose from his chair and passed urine.

The subject's lunch consisted of 112 grams of bananas, 463 grams of milk, 230 grams of ham (?) sandwich, and 65 grams of shelled nuts. The latter were not eaten immediately, but at various times during the remainder of the experiment. The subject voided 453 grams of urine during the experiment and drank 195 c. c. of water.

The subject said that soon after entering he noticed a peculiar odor in the chamber, but it was not disagreeable. At $10^h 35^m$ a. m., he seemed to think the air cooler than at the beginning, but it was not uncomfortable. Later he said the air was warm again. The subject was a machinist who had assisted in the building of various parts of the apparatus connected with the respiration calorimeter, and was very familiar with the running of all its parts, and therefore the sensation of novelty was absent. He was somewhat more active while inside the chamber than the previous subject.

The pulse records as taken by the subject were at $8^h 45^m$ a. m., 83; $11^h 20^m$ a. m., 67; $1^h 18^m$ p. m., 66; $3^h 15^m$ p. m., 67. The sublingual body-temperatures were at $9^h 16^m$ a. m., 98.3° F.; $11^h 16^m$ a. m., 97.7° F.; $1^h 16^m$ p. m., 98.3° F.; $3^h 16^m$ p. m., 97.8° F. The results of the metabolism obtained in this experiment are given in table 44.

METABOLISM EXPERIMENT No. 117.

Subject, S. C. D., June 21, 1905. (Same subject as in experiment No. 116.)

For breakfast the subject ate a dish of prepared cereal with cream and sugar, baked beans, bread and butter, and coffee with cream. He was weighed at $8^h 19^m$ a. m., and the experiment proper began at $9^h 17^m$ a. m. At this time the subject went to the food aperture and placed the thermometer in as usual, and also took out a bottle of water, part of which he drank immediately. At $9^h 46^m$ a. m. he again went to the food aperture and took out some writing materials, after which he sat down. At 11 a. m. he passed urine and then sat down. Between $11^h 17^m$ a. m. and $11^h 52^m$ a. m., he went to the food aperture five times. At $11^h 54^m$ a. m. he passed urine and then sat down. The subject opened the food aperture twice at 12 noon and again at $12^h 16^m$ p. m. During part of the time from $11^h 32^m$ a. m. he had been eating his lunch, which he had taken from the food aperture. After $1^h 17^m$ p. m. he went to the food aperture several times, and at $1^h 46^m$ p. m., passed urine. At $2^h 18^m$ p. m. the subject went to the food aperture again, and at $2^h 52^m$ p. m. passed urine. The experiment was finished at $3^h 17^m$ p. m. The lunch eaten by the subject con-

sisted of 187 grams of oranges, 158 grams of crackers, and 465 grams of milk. With his lunch he drank 438 c. c. of water. During the experiment he passed 922 grams of urine and drank a total of 888 c. c. of water. The subject stated that the air seemed close at times and that he had a slight headache, although he felt better during this than in the preceding experiment. He was also unusually active while in the chamber as compared with other experiments.

The pulse-rate as recorded by the subject was as follows: $8^h 35^m$ a. m., 88; $9^h 15^m$ a. m., 83; 12 noon, 68; $1^h 20^m$ p. m., 65; $3^h 15^m$ p. m., 70. The body-temperatures were sublingual and as follows: $9^h 17^m$ a. m., 98.2° F.; $11^h 17^m$ a. m., 97.8° F.; $1^h 17^m$ p. m., 98.1° F.; $3^h 17^m$ p. m., 98.3° F. The results of the metabolism in this experiment are given in table 44.

METABOLISM EXPERIMENT No. 118.

Subject, B. N., April 29, 1905. Age, 16 years 2 months; height, 168 cm.; weight without clothing, 45.8 kilos.

The subject entered the respiration calorimeter at about 8 a. m., after a breakfast taken about 1 hour before, consisting of 2 boiled eggs, 1 slice of bread, 1 cup of coffee, and 2 crackers. He was weighed at $9^h 04^m$ a. m., and then sat quietly until the experiment began at $9^h 44^m$ a. m. The experiment ended at $3^h 44^m$ p. m., and the measurements were made in three 2-hour periods.

At the beginning of the first period the subject rose from his chair, went to the food aperture, took out a bottle of water and placed the thermometer in the food aperture, then drank 193 c. c. of water, and sat down. At $10^h 30^m$ a. m., he passed 413 grams of urine. At the beginning of the second period, $11^h 45^m$ a. m., he arose from his chair and went through the usual operations in taking his temperature. At $11^h 55^m$ a. m., he again went to the food aperture to get his lunch and a bottle of water, the lunch consisting of 126 grams of nuts, 442 grams of milk, 174 grams of oranges, and 149 grams of sandwich. At the beginning of the third period, $1^h 45^m$ p. m., he opened the food aperture twice in taking his temperature, then sat down again. At $2^h 20^m$ p. m. he went to the rear of the calorimeter, then returned and sat down. The subject usually assisted in the routine of the experiments carried on in the laboratory, and therefore was familiar with the apparatus, although this was his first experience inside the respiration chamber.

The subject took his own pulse-rate, and the records were as follows: $8^h 30^m$ a. m., 77; $9^h 15^m$ a. m., 75; $9^h 45^m$ a. m., 64; $10^h 45^m$ a. m., 63; $11^h 30^m$ a. m., 65; $12^h 10^m$ p. m., 68; 1 p. m., 75; 2 p. m., 75; $2^h 45^m$ p. m., 64. The body-temperatures were sublingual and as follows: $9^h 44^m$ a. m., 98.5° F.; $11^h 44^m$ a. m., 98.4° F.; $1^h 44^m$ p. m., 98.8° F.; $3^h 44^m$ p. m., 98.6° F. The results of the metabolism are given in table 44.

METABOLISM EXPERIMENT No. 119.

Subject, B. N., June 5, 1905. (Same subject as in experiment No. 118.)

Before entering the respiration chamber the subject ate a light breakfast consisting of oatmeal, coffee, and crackers. He was weighed at $9^h\,12^m$ a. m. and the first period began at $10^h\,22^m$ a. m. The subject then placed the clinical thermometer in the food aperture and sat down and read, remaining quiet until $12^h\,22^m$ p. m., when he again went to the food aperture and procured the materials for his lunch. At $12^h\,34^m$ p. m. he began eating and finished at $12^h\,48^m$ p. m. At that time he rose from his chair and placed the uneaten food on the shelf inside the chamber. He returned to his chair and sat quietly until $2^h\,22^m$ p. m., when he went to the food aperture and placed the remainder of his lunch in it. He then sat down and remained quiet until the end of the experiment at $4^h\,22^m$ p. m. At the beginning of each period he followed the same routine in taking his temperature, opening the food aperture to get the thermometer, sitting down while taking the temperature, opening food aperture to replace the thermometer, and sitting down again.

The subject's lunch consisted of oranges, sandwiches, bananas, and dates, the total food eaten being 605 grams. He also drank 205 c. c. of water with his lunch. During the experiment 225 grams of urine were passed. This was the subject's second experiment inside the respiration chamber and no comments were made by him.

The pulse-rate as recorded by the subject was as follows: 10 a. m., 58; $10^h\,50^m$ a. m., 58; $11^h\,45^m$ a. m., 59; $12^h\,50^m$ p. m., 59; 2 p. m., 61; 3 p. m., 71; $3^h\,40^m$ p. m., 61; $4^h\,20^m$ p. m., 61. The sublingual body-temperatures were at $10^h\,22^m$ a. m., 97.8° F.; $12^h\,22^m$ p. m., 97.6° F.; $2^h\,22^m$ p. m., 98.1° F.; $4^h\,22^m$ p. m., 97.6° F. The results of the metabolism for the three 2-hour periods are given in table 44.

METABOLISM EXPERIMENT No. 120.

Subject, B. N., June 15, 1905. (Same subject as in experiment No. 118.)

Breakfast was eaten between 6 a. m. and 7 a. m. and consisted of oatmeal, egg, coffee, and a piece of cake. The subject entered the respiration chamber at about 9 a. m., was weighed at $9^h\,05^m$ a. m., and the experiment proper began at $10^h\,30^m$ a. m. The usual routine of taking the temperature was followed at the beginning of each period. At $12^h\,30^m$ p. m., in addition to this routine, the subject received his lunch and in doing this opened the food aperture several times. He began eating at $12^h\,42^m$ p. m. and finished at $12^h\,50^m$ p. m., at which time he put the remainder into the food aperture. The subject remained quiet until the end of the experiment at $4^h\,30^m$ p. m., except when taking the thermometer from the food aperture at $2^h\,30^m$ p. m., and replacing it. The lunch consisted of 58 grams of crackers, 309 grams of bananas, and

438 grams of milk. During the experiment the subject passed 530 grams of urine. The subject made no comments regarding the experiment.

The pulse-rate as recorded by the subject was as follows: $10^h 13^m$ a. m., 68; $10^h 50^m$ a. m., 60; $11^h 45^m$ a. m., 59; $1^h 10^m$ p. m., 65; 2 p. m., 70; 3 p. m., 68; $3^h 45^m$ p. m., 67. The body-temperatures taken sublingually with a clinical thermometer were as follows: $10^h 30^m$ a. m., 98.1° F.; $12^h 30^m$ p. m., 98.5° F.; $2^h 30^m$ p. m., 98.3° F.; $4^h 30^m$ p. m., 98.5° F. The results of the metabolism are given in table 44.

METABOLISM EXPERIMENT No. 121.

Subject, F. L. T., May 1, 1905. Age, 25 years 7 months; height, 192 cm.; weight without clothing, 64.3 kilos.

The subject entered the chamber at about 8 a. m. and was weighed at $8^h 17^m$ a. m. Shortly before entering the chamber he partook of a breakfast consisting of potatoes, beef, bread and butter, and coffee with milk and sugar. The experiment began at $9^h 23^m$ a. m. At the beginning of the first period the subject went to the food aperture, took out a bottle of water, and then returned to his chair. At the beginning of the second period, $11^h 23^m$ a. m., he went to the food aperture and opened it three times. At $12^h 16^m$ p. m. he rose and then began eating his lunch, which consisted of 467 grams of milk, 414 grams of oranges, 97 grams of crackers, and 73 grams of nuts; he finished at $12^h 36^m$ p. m. At that time he rose, passed 188 grams of urine and sat down again. At the latter part of this period he ate an orange and some nuts. At the beginning of each period the subject went through the usual routine in taking his temperature. The experiment ended at $3^h 23^m$ p. m., the measurements being taken in 2-hour periods. The subject drank 136 c. c. of water. The subject was a student in Wesleyan University, was entirely unfamiliar with the apparatus or any of its experiments, and was selected for this experiment because of his being above the average height. He made very little comment regarding his stay in the chamber, except to say that the air was good and the temperature comfortable, and that at first he was annoyed by the noise of the rotary blower.

The pulse-rate as recorded by the subject was as follows: $9^h 11^m$ a. m., 75; 10 a. m., 61; $10^h 45^m$ a. m., 55; $11^h 30^m$ a. m., 58; $12^h 15^m$ p. m., 56; 1 p. m., 78; $1^h 45^m$ p. m., 66; $2^h 30^m$ p. m., 64; $3^h 15^m$ p. m., 61. The sublingual body-temperatures were at $9^h 23^m$ a. m., 98.4° F.; $11^h 23^m$ a. m., 97.8° F.; $1^h 23^m$ p. m., 98.2° F.; $3^h 23^m$ p. m., 98.0° F. The results of the metabolism for the experiment are given in table 44.

METABOLISM EXPERIMENT No. 122.

Subject, W. R. L., May 2, 1905. Age, 24 years 6 months; height, 198 cm.; weight without clothing, 74.9 kilos.

The subject entered the respiration chamber at about 9 a. m., after a breakfast of coffee, oatmeal, and toast. He was weighed at $9^h 14^m$ a. m. From this time until the beginning of the experiment he remained seated in the chair. The experiment proper began at $10^h 28^m$ a. m. and at the beginning of each period the subject went through the usual routine in taking his temperature, and then sat down. At the beginning of the second period, $12^h 28^m$ p. m., he went to the food aperture and received his lunch. After taking his temperature, he went to the food aperture again to get a bottle of water and then sat down and began to eat the lunch, which consisted of 405 grams of bananas, 143 grams of crackers, 462 grams of milk, and 33 c. c. of water. He finished this at $1^h 02^m$ p. m. The experiment was finished at $4^h 28^m$ p. m. The subject was a student in Wesleyan University and was selected because of his height. It was his first experience as a subject inside the respiration chamber and he said he found the experiment monotonous and tiresome after he had been in a short time. He also said the air was good and the temperature comfortable.

The pulse-rate as recorded by the subject was at $10^h 19^m$ a. m., 70; $12^h 06^m$ p. m., 61; $1^h 55^m$ p. m., 75; $3^h 27^m$ p. m., 79; $4^h 12^m$ p. m., 67. The sublingual body-temperatures were at $10^h 28^m$ a. m., 98.4° F.; $12^h 28^m$ p. m., 97.3° F.; $2^h 28^m$ p. m., 98.° F.; $4^h 28^m$ p. m., 97.8° F. The results of the metabolism for the experiment are given in table 44.

METABOLISM EXPERIMENT No. 123.

Subject, W. H. L., May 9, 1905. Age, 31 years 7 months; height, 174 cm.; weight without clothing, 63.1 kilos.

Shortly before entering the calorimeter at 8 o'clock, the subject had eaten breakfast consisting of a prepared cereal with milk and sugar, a slice of bread and butter, a cruller, and a glass of water. He was weighed at $8^h 02^m$ a. m. and the experiment proper began at $9^h 43^m$ a. m. At the beginning of each period the subject went through the usual routine in taking his temperature. At the beginning of the second period, $11^h 43^m$ a. m., he went to the food aperture and took out the dishes and food for his lunch, rising and opening the food aperture three times during the process. His lunch consisted of 154 grams of bananas, 137 grams of bread and butter, 57 grams of eggs, 113 grams of milk, 22 grams of sugar, and 93 c. c. of water. At $11^h 58^m$ a. m. he rose, passed 243 grams of urine, and sat down. From 12 noon until $12^h 28^m$ p. m. lunch was eaten. At $12^h 36^m$ p. m. he rose from his chair and then sat down. He went to the food aperture at $2^h 04^m$ p. m. to put in one of the dishes from his lunch and then sat down again. The experiment ended at $3^h 43^m$ p. m.

The subject was a computer in connection with the nutrition investigations, and also at times assisted as an observer in connection with the respiration

calorimeter experiments. He stated in his observations that during the first period his head was a little heavy and warm, but otherwise he was quite comfortable. He noticed the noise of the blower, and said the air was all right. At 1^h 34^m p. m. he stated the air did not seem as pure as it was before. At 2^h 30^m p. m. he said he felt warm and the air was not as good. At 3^h 04^m p. m. he stated his eyes were tired but he was not sleepy.

The pulse-rate as recorded by the subject was as follows: 8^h 24^m a. m., 77; 8^h 50^m a. m., 81; 10^h 10^m a. m., 72; 10^h 49^m a. m., 60; 10^h 51^m a. m., 65; 10^h 54^m a. m., 64; 11^h 32^m a. m., 61; 12^h 38^m p. m., 75; 1^h 06^m p. m., 67; 1^h 33^m p. m., 70; 1^h 55^m p. m., 75; 2^h 28^m p. m., 75; 3^h 03^m p. m., 72; 3^h 33^m p. m., 67. The sublingual body-temperatures were at 9^h 43^m a. m., 98.6° F.; 11^h 43^m a. m., 98.2° F.; 1^h 43^m p. m., 98.4° F.; 3^h 43^m p. m., 98.4° F. The results of the metabolism for the experiment, as measured in three 2-hour periods, are given in table 44.

METABOLISM EXPERIMENT No. 124.

Subject, W. H. L., June 6, 1905. (Same subject as in experiment No. 123.)

Before entering the calorimeter, the subject ate a breakfast consisting of prepared cereal with sugar and cream, 1 slice of bread and butter, and 1 cruller. He was weighed at 8^h 08^m a. m. and the experiment began at 9^h 07^m a. m. The usual routine in taking the body-temperature was followed at the beginning of each period. At the beginning of the first period the subject rose, went to the food aperture, put the thermometer in, then sat down and read until 9^h 34^m a. m., when he again went to the food aperture. He then sat down and resumed reading and read until the beginning of the next period, 11^h 07^m a. m., when he again went to the food aperture to get the thermometer. In doing so he upset the table. The rearrangement of the furniture necessitated a considerable number of movements, after which he again sat down and took his pulse, and then rose and passed urine. At 12^h 14^m p. m. he went to the food aperture and received his lunch. In doing this he opened the food aperture four times. He began to eat at 12^h 28^m p. m. and had finished at 12^h 50^m p. m. The lunch eaten by the subject consisted of 60 grams of milk, 44 grams of sugar, 45 grams of crackers, 152 grams of strawberries, 47 grams of sandwich, and 66 c. c. of water. Between 1^h 25^m and 1^h 45^m p. m. the subject rose three times and went to the food aperture and sent out from the chamber dishes and food from his lunch, then passed urine, and sat down. At 2^h 06^m p. m. he ate a few strawberries. He then continued reading until the end of the experiment at 3^h 07^m p. m. The subject passed 519 grams of urine during the experiment. He reported that he was very comfortable throughout the experiment, although his head became tired during the latter part, which was due, he thought, to reading.

The pulse-rate as recorded by the subject was as follows: 9^h 01^m a. m., 70; 10^h 08^m a. m., 59; 10^h 11^m a. m., 62; 11^h 17^m a. m., 61; 12^h 26^m p. m., 65;

$1^h 18^m$ p. m., 70; $2^h 04^m$ p. m., 74; $2^h 59^m$ p. m., 70. The sublingual body-temperatures were at $9^h 07^m$ a. m., 98.2° F.; $11^h 07^m$ a. m., 98.2° F.; $1^h 07^m$ p. m., 98.8° F.; $3^h 07^m$ p. m., 98.7° F. The results of the metabolism for this experiment are given in table 44.

METABOLISM EXPERIMENT No. 125.

Subject, F. W. H., May 10, 1905. Age, 33 years 8 months; height, 173 cm.; weight without clothing, 58.4 kilos.

The subject ate breakfast consisting of 2 slices of toasted bread and 2 small cups of coffee with cream and sugar, and then entered the respiration chamber shortly after 8 a. m. He was weighed at $8^h 23^m$ a. m. and then sat down and remained quiet until the beginning of the experiment, which was at $9^h 13^m$ a. m. At the beginning of each period he went through the usual routine in taking his temperature. Soon after the beginning of the second period the subject went to the food aperture to get paper, food, and water, and rose three times and opened the food aperture three times during the process. At about $11^h 40^m$ a. m. the subject began to eat a lunch consisting of 392 grams of oranges, 194 grams of sandwich, and 412 grams of milk. He continued eating at various times until about $1^h 40^m$ p. m. At $12^h 58^m$ p. m. he passed 256 grams of urine, and at $1^h 05^m$ p. m. he stood up while drinking milk and then sat down. The subject rose and went to the food aperture at $1^h 44^m$ p. m. to take out a book and then sat down and read during the remainder of the experiment. The experiment was finished at $3^h 13^m$ p. m. and the measurements were made in three 2-hour periods. The subject made no comments regarding his experience. He was a computer in connection with the nutrition investigations and was somewhat familiar with the apparatus.

The subject took his pulse only twice during the experiment: at $10^h 20^m$ a. m., it was 78; and at $1^h 50^m$ p. m., it was 67. The sublingual body-temperatures were at $9^h 13^m$ a. m., 98.7° F.; $11^h 13^m$ a. m., 98.6° F.; $1^h 13^m$ p. m., 98.4° F.; $3^h 13^m$ p. m., 98.0° F. The results of the metabolism as determined in the three 2-hour periods are given in table 44.

METABOLISM EXPERIMENT No. 126.

Subject, J. R., May 11, 1905. Age, 22 years 10 months; height, 183 cm.; weight without clothing, 69.2 kilos.

Before entering the calorimeter at 8 a. m. the subject ate breakfast, consisting of 1 banana, 1 small dish of prepared cereal, 2 sausages, and 1 fried potato cake. He was weighed at $8^h 08^m$ a. m., and then remained quiet until the beginning of the experiment at 9 a. m. At the beginning of each period he went through the usual routine in taking his temperature. After observing his temperature and securing a book from the food aperture at $9^h 04^m$ a. m. the subject sat down and read until the beginning of the second period at 11 a. m. At $11^h 20^m$ a. m. he went to the food aperture to get his lunch and

made a number of movements while doing this. He ate lunch until about $11^h 40^m$ a. m. The lunch consisted of 177 grams of sandwich, 574 grams of oranges, 238 grams of milk, and 115 c. c. of water. After eating his lunch he remained quiet and read till the end of the experiment, except when observing his temperature and pulse.

The subject was an assistant in the respiration-calorimeter experiments, and although this was his first experience inside the chamber, he made very little comment, except to say that the air was good and that the temperature appeared to be somewhat lower about noon.

The pulse-rate as taken by the subject was as follows: $9^h 02^m$ a. m., 80; $9^h 30^m$ a. m., 77; $10^h 30^m$ a. m., 70; $11^h 35^m$ a. m., 68; $12^h 15^m$ p. m., 64; $1^h 15^m$ p. m., 67; $2^h 15^m$ p. m., 69; $2^h 50^m$ p. m., 66. The sublingual body-temperatures were at 9 a. m., 98.0° F.; 11 a. m., 97.9° F.; 1 p. m., 98.1° F.; 3 p. m., 98.0° F. The results of the metabolism in this experiment, as measured in three 2-hour periods, are given in table 44.

METABOLISM EXPERIMENT No. 127.

Subject, R. D. M., May 12, 1905. Age, 35 years 9 months; height, 178 cm.; weight without clothing, 70.4 kilos.

After a breakfast consisting of crackers and milk, the subject entered the calorimeter at $7^h 45^m$ a. m. and was weighed at $7^h 58^m$ a. m. He then seated himself in the chair and remained quiet until $8^h 48^m$ a. m., when the experiment began. At the beginning of each period the subject followed the usual routine in taking his temperature. At $8^h 52^m$ a. m. he commenced working on a manuscript and occupied all his time during the first period in reading this manuscript, except that at $9^h 12^m$ a. m. he went to the food aperture to get a sheet of paper. During the second period he read until $11^h 50^m$ a. m. At that time he opened the food aperture three times without getting up from his chair and took out his lunch. He was eating between $11^h 50^m$ a. m. and $12^h 24^m$ p. m. During this time he went to the food aperture once to get a knife and then sat down. The lunch consisted of 120 grams of sandwich, 320 grams of oranges, 150 grams of bananas, and 466 grams of milk. At 1 p. m. the subject replaced the thermometer in the food aperture and then during the rest of the time until the finish of the experiment at $2^h 48^m$ p. m. he was reading.

The subject was an editorial assistant in the nutrition investigations and this was his first experience as a subject inside the respiration chamber. He was affected by his sojourn in the chamber, although this effect did not take place until after he had left the laboratory. The details regarding this indisposition have been given by us elsewhere.[1]

The pulse-rate as taken by the subject was as follows: $8^h 30^m$ a. m., 77; 9 a. m., 77; 10 a. m., 68; 11 a. m., 63; 12 noon, 63; 1 p. m., 62; 2 p. m., 67;

[1] Carpenter and Benedict, Am. Journ. Physiol., 1909, 24, p. 187.

3 p. m., 66. The sublingual body-temperatures were at $8^h 48^m$ a. m., 98.0° F.; $10^h 48^m$ a. m., 97.6° F.; $12^h 48^m$ p. m., 97.5° F.; $2^h 48^m$ p. m., 97.7° F. The results of the metabolism in this experiment, as measured in the three 2-hour periods, are given in table 44.

METABOLISM EXPERIMENT No. 128.

Subject, R. A. M., June 8, 1905. Age, 31 years 11 months; height, 166 cm.; weight without clothing, 65 kilos.

The subject entered the respiration chamber shortly after 8 a. m., after having eaten a breakfast consisting of 1 roll, 1 cup of coffee, a small amount of potato, stewed dried beef, 1 banana, and a dish of prepared cereal. He was weighed at $8^h 17^m$ a. m. and the experiment began at $9^h 24^m$ a. m., when the subject went to the food aperture to put in the thermometer with which he had taken his temperature. The usual routine in the body-temperature observations was followed during the experiment. Soon after the beginning of the second period the subject went to the food aperture to get his lunch, which consisted of 441 grams of milk and 206 grams of cheese sandwich. He began eating at $11^h 42^m$ a. m. and finished at $11^h 56^m$ a. m. Most of the time during the remainder of the experiment was spent in reading. The experiment ended at $3^h 24^m$ p. m., there having been three 2-hour periods. The subject was an assistant in the experiments and made no comments regarding his experience, except to say that he was slightly chilly all of the time.

The pulse-rate per minute as recorded by the subject was as follows: $9^h 26^m$ a. m., 71; $10^h 26^m$ a. m., 72; $11^h 29^m$ a. m., 65; $12^h 34^m$ p. m., 66; $1^h 35^m$ p. m., 70; $2^h 38^m$ p. m., 70. The sublingual body-temperatures were at $9^h 24^m$ a. m., 98.5° F.; $11^h 24^m$ a. m., 98.3° F.; $1^h 24^m$ p. m., 98.3° F.; $3^h 24^m$ p. m., 98.0° F. The results of the metabolism in the experiment are given in table 44.

METABOLISM EXPERIMENT No. 129.

Subject, R. A. M., June 13, 1905. (Same subject as in experiment No. 128.)

Previous to going into the calorimeter the subject ate breakfast, consisting of a cup of coffee, a dish of prepared cereal, a banana, a small piece of salt mackerel, a small amount of potato, and a slice of bread. He was weighed at $8^h 22^m$ a. m. and the experiment began at $9^h 42^m$ a. m., when the subject went to the food aperture and put the thermometer in. He took his temperature at the beginning of each period and followed the usual routine in making the observation. At $11^h 54^m$ a. m., he rose and took his lunch from the food aperture and commenced eating at $11^h 58^m$ a. m., finishing at $12^h 12^m$ p. m. The food consisted of 184 grams of cheese sandwich and 452 grams of milk. The subject read most of the remaining time until the experiment ended at $3^h 42^m$ p. m. The subject reported that he felt somewhat chilly, but not enough to cause discomfort.

The pulse-rate as recorded by the subject was as follows: $9^h 51^m$ a. m., 66; $10^h 47^m$ a. m., 62; $11^h 48^m$ a. m., 56; $1^h 01^m$ p. m., 61; 2 p. m., 66; $3^h 17^m$ p. m., 62. The sublingual body-temperatures were as follows: $9^h 42^m$ a. m., 97.8° F.; $11^h 42^m$ a. m., 97.8° F.; $1^h 42^m$ p. m., 97.9° F.; $3^h 42^m$ p. m., 97.8° F. The results of the metabolism in the experiment are recorded in table 44.

METABOLISM EXPERIMENT No. 130.

Subject, H. L. K., June 10, 1905. Age, 23 years 8 months; height, 166 cm.; weight without clothing, 55.4 kilos.

The subject entered the respiration chamber at about $7^h 30^m$ a. m., after eating a breakfast consisting of 1 banana, 6 tablespoonfuls of prepared cereal with cream, 1 egg, 1 biscuit, 1 doughnut, and 1 cup of coffee with cream and sugar. He was weighed at $7^h 39^m$ a. m. and the experiment began at $8^h 39^m$ a. m. The subject in this experiment followed the usual routine of going to the food aperture at the beginning of each period in order to get a clinical thermometer to take his temperature and returning the thermometer after using it. He went to the food aperture at $9^h 14^m$ a. m. to put in some letters. At $11^h 32^m$ a. m. he rose from his chair and went to the food aperture and opened it four times in getting his lunch; each time after opening the food aperture he went to the front of the chamber, then returned, and finally sat down at $11^h 40^m$ a. m. At this time he began his lunch, eating 220 grams of bananas, 92 grams of crackers, 107 grams of cream, and 316 grams of milk, finishing at $12^h 04^m$ p. m. At $12^h 40^m$ p. m. the subject passed 285 grams of urine and placed the uneaten portion of his lunch in the food aperture. At $1^h 30^m$ p. m. he again went to the food aperture for some paper. The experiment ended at $2^h 39^m$ p. m.

This subject, who was connected with the investigations as an editorial assistant, had been in two previous experiments[1] and said that during this experiment the air seemed warm and close at the beginning, and that he was nervous, but that this was not due to the experiment itself.

The pulse-rate as recorded by the subject was as follows: $7^h 48^m$ a. m., 101; 8 a. m., 100; $8^h 15^m$ a. m., 94; $8^h 30^m$ a. m., 98; $9^h 10^m$ a. m., 100; $9^h 30^m$ a. m., 89; $10^h 10^m$ a. m., 83; $10^h 35^m$ a. m., 78; 11 a. m., 66; $11^h 30^m$ a. m., 73; $12^h 15^m$ p. m., 75; $12^h 53^m$ p. m., 76; $1^h 30^m$ p. m., 90; $2^h 10^m$ p. m., 83. The sublingual body-temperatures were as follows: $8^h 39^m$ a. m., 98.6° F.; $10^h 39^m$ a. m., 98.5° F.; $12^h 39^m$ p. m., 98.8° F.; $2^h 39^m$ p. m., 98.9° F. The results of the metabolism in the three 2-hour periods are given in table 44.

METABOLISM EXPERIMENT No. 131.

Subject, H. A. P., June 12, 1905. Age, 27 years; height, 180 cm.; weight without clothing, 63.9 kilos.

The subject ate breakfast, which consisted of bread and butter and coffee, and soon after this meal he entered the respiration chamber. He was weighed at

[1] Benedict and Carpenter, U. S. Dept. Agr., Office Exp. Stas. Bul. 208, 1909.

$8^h\ 13^m$ a.m. and then remained quiet until the beginning of the experiment at $9^h\ 44^m$ a.m. He followed the same routine as in previous experiments in regard to taking his temperature, placing the thermometer in the food aperture each time after using it. Soon after the beginning of the first period he passed urine. At $11^h\ 06^m$ a.m. he stood up and sat down again. At $12^h\ 05^m$ p.m. he passed urine and then opened the food aperture to get his lunch. Between $12^h\ 10^m$ p.m. and $12^h\ 30^m$ p.m. he ate 188 grams of crackers and 452 grams of milk, then moved about, and finally sat down. During the rest of the experiment he was comparatively quiet, except for certain changes of position. The experiment ended at $3^h\ 39^m$ p.m. During the experiment 3.44 grams of urine were passed.

The subject was an editorial assistant in the nutrition investigations, and this was his first experience inside the respiration chamber. He said that most of the time he was very uncomfortable and very cold, particularly around his feet and ankles, and below his knees.

The pulse-rate as recorded by the subject was as follows: $9^h\ 30^m$ a.m., 95; $9^h\ 35^m$ a.m., 95; $10^h\ 30^m$ a.m., 87; $10^h\ 35^m$ a.m., 85; $11^h\ 30^m$ a.m., 74; $11^h\ 35^m$ a.m., 74; $12^h\ 30^m$ p.m., 89; $12^h\ 35^m$ p.m., 87; $1^h\ 30^m$ p.m., 86; $1^h\ 35^m$ p.m., 87; $2^h\ 35^m$ p.m., 81; $3^h\ 40^m$ p.m., 82. The sublingual body-temperatures taken were $9^h\ 44^m$ a.m., 98.6° F.; $11^h\ 44^m$ 98.0° F.; $1^h\ 44^m$ p.m., 98.1° F.; $3^h\ 44^m$ p.m., 97.8° F. The measurements were made in three 2-hour periods and the results of the metabolism are given in table 44.

METABOLISM EXPERIMENT No. 132.

Subject, H. A. P., June 20, 1905. (Same subject as in experiment No. 131.)

The subject entered the respiration chamber at 8 a.m., having had a breakfast shortly before, consisting of green peas, bread and butter, coffee, and ginger cakes. He was weighed at $8^h\ 22^m$ a.m. and the experiment began at $9^h\ 10^m$ a.m. The subject followed the routine of taking the temperature and replacing the thermometer in the food aperture at the beginning of each period. At $10^h\ 50^m$ a.m. he passed urine. Between $11^h\ 42^m$ a.m. and $11^h\ 56^m$ a.m. he went to the food aperture four times in getting his lunch. The subject began eating at 12 o'clock and finished at $12^h\ 14^m$ p.m. At $12^h\ 44^m$ p.m. he went to the food aperture and placed therein the dishes which he had used in eating his lunch. The lunch consisted of 444 grams of milk and 181 grams of crackers. Between $2^h\ 18^m$ and $2^h\ 34^m$ p.m. the subject twice changed the position of his chair in the chamber, and at $2^h\ 42^m$ p.m. he set up the table. At $2^h\ 44^m$ p.m. he passed urine. At $3^h\ 10^m$ p.m. the experiment ended. During the experiment 440 grams of urine were passed. In his remarks he stated that he was dressed somewhat more heavily than in the previous experiment, and that he perspired some. He also said that some of the food did not taste well, but that possibly this was due to imagination.

The pulse-rate as recorded by the subject was as follows: $8^h 32^m$ a. m., 104; $9^h 30^m$ a. m., 95; $10^h 45^m$ a. m., 88; $11^h 30^m$ a. m., 83; $12^h 50^m$ p. m., 84; $1^h 43^m$ p. m., 77; $1^h 45^m$ p. m., 78; $2^h 32^m$ p. m., 77. The sublingual body-temperatures were $9^h 10^m$ a. m., 98.5° F.; $11^h 10^m$ a. m., 98.3° F.; $1^h 10^m$ p. m., 98.0° F.; $3^h 10^m$ p. m., 97.5° F. The results of the metabolism in the experiment are given in table 44.

METABOLISM EXPERIMENT No. 133.

Subject, W. E. D., June 14, 1905. Age, 20 years 4 months; height, 179 cm.; weight without clothing, 74.4 kilos.

Before entering the respiration calorimeter the subject had a breakfast, consisting of oatmeal with milk and sugar, whole-wheat gems with butter, a potato cake, and water. He was weighed at $8^h 15^m$ a. m. and the experiment began at $9^h 22^m$ a. m. The subject at that time took his temperature, subsequently putting the thermometer in the food aperture, and the usual routine in taking body-temperature was carried out at the beginning of each period. At $11^h 48^m$ a. m. he went to the food aperture, took out his lunch and commenced eating at $11^h 50^m$ a. m. He again opened the food aperture at $11^h 58^m$ a. m. to procure more food, and stopped eating at $12^h 14^m$ p. m. The food eaten during the experiment consisted of 120 grams of milk, 120 grams of crackers, 53 grams of cheese, 401 grams of oranges, and 101 c. c. of water. At $12^h 40^m$ p. m. he ate one of the oranges from his lunch. At $1^h 42^m$ p. m. he ate another orange, and at $2^h 14^m$ p. m. passed out the uneaten portion of his lunch. At $3^h 22^m$ p. m. the experiment ended. The subject passed 228 grams of urine during the experiment.

This experiment was the first with this subject, who was a student in Wesleyan University and also assisted in the respiration-calorimeter experiments. He made no comments regarding his experience.

The pulse-rate as recorded by the subject was as follows: $9^h 40^m$ a. m., 65; $11^h 30^m$ a. m., 55; $1^h 35^m$ p. m., 58; $3^h 10^m$ p. m., 58. The sublingual body-temperatures were at $9^h 22^m$ a. m., 98.3° F.; $11^h 22^m$ a. m., 97.6° F.; $1^h 22^m$ p. m., 98.4° F.; $3^h 22^m$ p. m., 98.4° F. The results of the metabolism in this experiment are given in table 44.

METABOLISM EXPERIMENT No. 134.

Subject, C. R. Y., October 4–5, 1905. Age, 19 years 9 months; height, 170 cm.; weight without clothing, 64.5 kilos.

The experiment was originally planned to study the metabolism during the digestion of different kinds of cheese, and the diet consisted of cheese, bread, and bananas. The experiment began at 1 p. m., October 4, although the subject had entered the respiration chamber previous to this some time during the morning. The measurements were made in three 6-hour periods, the first from 1 p. m. to 7 p. m., October 4; the second from 7 p. m., October 4, to 1 a. m., October 5; and the third from 1 a. m. to $7^h 10^m$ a. m., October 5. The subject was a student in Wesleyan University.

At the beginning of the first period the subject passed urine and took his own temperature. He then suspended the weighing-chair and after being weighed assisted in weighing the bed-clothing. Between $1^h 26^m$ p. m. and $1^h 52^m$ p. m. he went to the food aperture five times in procuring the portion of the food assigned for the experiment, and during this time he ate a certain amount for his dinner. He then read until 4 p. m. Between 4 p. m. and $4^h 20^m$ p. m. the subject was walking, and from $4^h 24^m$ p. m. until $5^h 48^m$ p. m. was reading, except that he went to the food aperture twice. Between 6 p. m. and $6^h 26^m$ p. m. he was eating supper. The total amount of food eaten in the two meals was 114 grams of cheese, 260 grams of bread, and 450 grams of bananas. At $7^h 02^m$ p. m. the subject passed 186 grams of urine and then continued his reading. Just before 11 p. m. he took down the bed, passed urine, undressed, and retired. He slept until 7 a. m., at which time he was called, and shortly afterwards was taken out of the chamber because he could not complete the experiment on account of the unpalatability of the diet. Between $10^h 45^m$ p. m., October 4, and the end of the experiment, the subject passed 558 grams of urine.

The body-temperatures, taken by means of the clinical thermometer, were 97.6° F. at 1 p. m., October 4; 98.3° F. at 7 p. m., October 4; and 97.7° F. at $7^h 40^m$ a. m., October 5, the usual routine being followed each time. The pulse and respiration were not recorded. The results for the metabolism of the three 6-hour periods are given in table 44.

METABOLISM EXPERIMENT No. 135.

Subject, C. R. Y., February 8, 1906. (Same subject as in experiment No. 134.)

The subject entered the respiration chamber without breakfast and was weighed at $8^h 08^m$ a. m. The first period began at $9^h 15^m$ a. m. The experiment was planned for the purpose of obtaining the metabolism of this subject after a 12-hour fast, but although he had been the subject in several previous experiments, he was so restless that it was decided to take him out of the respiration chamber at $12^h 20^m$ p. m. For the particular experiment planned with this subject, the greatest possible muscular control was highly desirable. Only one period was made, from $9^h 15^m$ a. m. to $11^h 15^m$ a. m.

TABLE 22.—*Record of pulse and respiration—Metabolism experiment No. 135.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906 Feb. 8 A. M.			1906 Feb. 8 A. M.			1906 Feb. 8 A. M.		
$8^h 58^m$	57	17	$10^h 08^m$	..	18	$10^h 53^m$	..	16
9 19	..	18	10 18	62	..	11 07	..	17
9 27	50	..	10 23	58	..	11 10	..	16
9 32	52	..	10 28	..	17	11 13	55	..
9 36	56	..	10 45	..	17	11 45	..	18
9 55	..	17	10 48	57	..			

The pulse and respiration were recorded by the pneumograph and are given in table 22.

The rectal body-temperature taken with an electrical-resistance thermometer was at $9^h 15^m$ a. m., 36.40° C.; at $11^h 15^m$ a. m. it was 36.76° C. During this period the water vaporized was 59.4 grams, the carbon dioxide eliminated was 58.7 grams, and the oxygen absorbed 51.8 grams. The heat elimination was 173.3 calories, and the heat production 194.4 calories.

METABOLISM EXPERIMENT No. 136.

Subject, F. G. B., October 23, 1905. Age, 35 years; height, 183 cm.; weight without clothing, 83.2 kilos.

The subject (a chemist) entered the chamber at 4 p. m. No record was made of the food eaten at the last meal. The first period began at $5^h 46^m$ p. m., and previous to this the subject sat quietly in the chair most of the time. The experiment continued until $9^h 46^m$ p. m., the measurements being made in two 2-hour periods. At $5^h 52^m$ p. m., the subject drank about 100 c. c. of water. At 7 p. m. he passed urine. At $7^h 05^m$ p. m. he went to the food aperture and received his lunch, which consisted of 450 grams of milk, 4 slices of entire wheat bread with butter, and 75 c. c. of water. He began to eat immediately and while eating telephoned a number of times, and there was more or less muscular movement. The first period ended at $7^h 51^m$ p. m. During the second period the subject was comparatively quiet, reading most of the time. He drank about 150 c. c. of water at $8^h 30^m$ p. m. The comment made by the subject was that he was slightly irritated by the presence of formaldehyde, which had been used for disinfecting the chamber some time before.

The pulse-rate as recorded by the subject was as follows: $4^h 04^m$ p. m., 84; $4^h 50^m$ p. m., 88; 6 p. m., 76; $6^h 30^m$ p. m., 75; 7 p. m., 73; $7^h 50^m$ p. m., 70; $8^h 25^m$ p. m., 73; $8^h 56^m$ p. m., 73; $9^h 38^m$ p. m., 70. The sublingual body-temperatures recorded by the subject were as follows: $5^h 44^m$ p. m., 98.6° F.; $7^h 50^m$ p. m., 98.5° F.; $9^h 48^m$ p. m., 97.8° F. The results of the metabolism in the two periods are given in table 44.

METABOLISM EXPERIMENT No. 137.

Subject, A. H. M., November 13–14, 1905. Age, 24 years 1 month; height, 179 cm.; weight without clothing, 61.7 kilos.

This experiment was planned to determine whether it was possible for a man to remain in the calorimeter over night without suffering any ill effects from his sojourn. Previous to this experiment the subject, a student, had been in the calorimeter and had become sick as a result of mercurial poisoning. The experiment in which the subject became ill and the experiment here reported have both been briefly reported by us in a previous publication.[1] The subject entered the respiration chamber at about 3 p. m., and the measurements began at 5 p. m. Immediately after the beginning of the first period the subject was weighed in the chair and then the bed-clothing, which he had

[1] Carpenter and Benedict, Am. Journ. Physiol., 1909, **24**, p. 203.

in with him, and other articles were placed upon the chair and weighed. The chair was then removed from the suspension rod by the subject and he sat down and remained quiet until 6 p. m., when he went to the food aperture to remove the materials for his supper. The subject finished eating at $6^h 36^m$ p. m., having eaten 190 grams of bread, 40 grams of cheese, 13 grams of butter, and 256 grams of milk. After he had finished eating he put the remainder of the food on the shelf. At the beginning of the next period he stood up and went to the food aperture several times, while putting in the articles left from his supper. Soon afterwards he sat down and remained quiet until he went to the food aperture at 8 p. m. to get a thermometer, and after taking his temperature he replaced the thermometer. At $8^h 34^m$ p. m. he went to the food aperture to get a bottle of water. Shortly after 9 p. m. he stood up. At $9^h 50^m$ p. m. he rose again and went to the food aperture. Between 10 and 11 p. m. the subject was very drowsy. At 11 p. m. he arranged the furniture, passed urine, undressed, and retired for the night.

The subject rose the next morning at 7 o'clock and dressed at once, then suspended the chair and was weighed. After getting out of the chair he placed the bed-clothes in it to be weighed, and after this operation was finished he took the chair down and set up the table for reading. At $7^h 52^m$ a. m. he went to the food aperture and took out his breakfast, of which he ate 87 grams of bread, 101 grams of bananas, and 227 grams of milk. At $8^h 10^m$ a. m. the subject finished eating, and put the uneaten portion of the food in the food aperture. He then took down the table, made up the bed, and very soon afterwards lay down. At $9^h 08^m$ a. m., the subject adjusted the rectal thermometer and lay down again. The subject got up, and urinated at $10^h 44^m$ a. m. He then remained lying down until $11^h 48^m$ a. m. when he rose and went to the food aperture. The experiment ended at $12^h 15^m$ p. m. The subject passed 735 grams of urine during the experiment.

He stated that he slept soundly and felt perfectly well during the experiment.

TABLE 23.—*Record of pulse and respiration—Metabolism experiment No. 137.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1905.			1905.			1905.		
Nov. 13.			Nov. 14.			Nov. 14.		
P. M.			A. M.			A. M.		
$4^h 00^m$	..	25	$12^h 56^m$	43	15	$4^h 41^m$	43	..
4 05	68	..	1 35	..	18	4 54	..	18
4 43	..	24	1 45	40	18	5 07	40	..
4 46	60	..	2 05	..	17	5 35	..	15
5 32	..	19	2 10	41	..	5 38	..	16
5 35	58	..	2 30	..	15	5 45	42	..
6 17	59	19	2 34	41	..	6 05	..	22
6 45	..	25	2 55	..	16	6 09	..	18
7 40	..	22	2 58	40	..	6 55	44	..
9 53	44	23	3 35	..	18	8 32	..	23
Nov. 14.			3 38	..	17	8 36	65	..
A. M.			3 43	40		9 17	49	24
$12^h 07^m$	..	15	4 07	..	17	10 44	..	25
12 11	..	15	4 11	..	15	10 52	48	..
12 14	41	..	4 22	41	..	P. M.		
12 34	..	15	4 34	..	16	12 01	43	24
12 38	40	..	4 38	..	17			

The pulse and respiration were taken by means of the pneumograph, and are given in table 23. The body-temperature was taken by means of the electrical-resistance rectal thermometer.

November 13:	°C.	November 14:	°C.
$5^h\ 00^m$ p. m.	37.00	$9^h\ 12^m$ a. m.	36.98
6 00 p. m.	36.75	10 00 a. m.	37.12
7 00 p. m.	36.69	11 00 a. m.	37.16
8 00 p. m.	36.65	12 12 p. m.	37.25

The measurements for the carbon-dioxide and water output, oxygen absorption, heat production, and heat elimination are given in table 44.

METABOLISM EXPERIMENT No. 138.

Subject, A. H. M., January 29, 1906. (Same subject as in experiment No. 137.)

This and the two following experiments were carried out with one subject to obtain information on the question of the difference in metabolism when the subject was standing, sitting in a chair, or lying upon a bed covered with a double blanket.

The subject entered the respiration chamber at about 8 a. m. after a normal breakfast. No record was made of the food eaten. During the morning period from $9^h\ 11^m$ a. m. to $12^h\ 11^m$ p. m. the subject was lying upon the bed, covered with a double cotton blanket. He was very quiet, and as evidence that he was awake all of the time, every 10 minutes he pressed a push-button which rang a bell in the laboratory. The subject rose at $9^h\ 16^m$ a. m. and remade the bed. The body-temperatures were measured sublingually by a clinical thermometer, and for this period were at $9^h\ 11^m$ a. m., 97.8° F.; $12^h\ 11^m$ p. m., 98.1° F.

After the period in bed was finished, the subject rose, made his bed, opened the food aperture to procure food for his lunch, and ate until $12^h\ 54^m$ p. m., at which time he passed out the uneaten food. After he had finished eating he sat down in the chair and remained quietly seated until the end of the experiment, except at $1^h\ 29^m$ p. m., when he went to the food aperture. The afternoon period continued from $1^h\ 29^m$ p. m. until $4^h\ 29^m$ p. m. The body-temperature taken by the subject sublingually at the beginning of this period was 98.4° F.; and at the end, 98.1° F. The measurements of the metabolism were made in two 3-hour periods and one intermediate period, and the results are recorded in table 44. The records of the pulse and respiration for these periods are given in table 24.

The results for this experiment show that the carbon-dioxide excretion per hour for the period lying awake was 27.4 grams and for sitting, 32.7 grams or 16.2 per cent less while lying awake. Similar comparisons for the oxygen absorbed, heat produced, and water vaporized show, respectively, 15.1, 25.2, and 2 per cent less while lying awake. The digestive processes were practically the same for both the above conditions since the subject had eaten before each period.

TABLE 24.—*Record of pulse and respiration—Metabolism experiment No. 138.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Jan. 29. A. M.			1906. Jan. 29. A. M.			1906. Jan. 29. P. M.		
9^h 50^m	..	14	11^h 42^m	..	16	3^h 53^m	..	16
10 28	..	11	P. M.			3 56	57	..
11 00	..	18	1^h 58^m	..	16	4 07	68?	18
11 14	..	16	2 06	60	..			

METABOLISM EXPERIMENT No. 139.

Subject, A. H. M., January 30, 1906. (Same subject as in experiment No. 137.)

The experiment on this day was a comparison of the metabolic activity when standing in the morning with that when lying down covered with a double blanket in the afternoon. At the beginning of the morning period the subject went to the food aperture and placed in it the clinical thermometer, and then stood still during the remainder of the 3-hour period, not leaning, and the only movement he made was occasionally to change his position. He read part of the time. The period after the usual time of preparation began at 9^h 45^m a. m. and ended at 12^h 45^m p. m. The subject said that he felt tired at the end of this period and that his back ached somewhat. At 12^h 45^m p. m. he went to the food aperture, sat down to take his temperature, and then replaced the thermometer. At 1^h 02^m p. m. he ate his lunch and at 1^h 35^m p. m. he lay down and covered himself with a blanket, and remained lying quietly until the end of the experiment. The afternoon period of lying down extended from 3^h 15^m p. m. to 6^h 15^m p. m. During the lying-down period the subject was occasionally sleepy, although he came out of the chamber feeling in excellent form. While he was lying down, the subject used the push-button in order to inform the observer outside that he was awake.

Records of pulse and respiration were obtained with the pneumograph and were as shown in table 25. The body-temperatures were taken sublingually by means of a clinical thermometer and were at 9^h 45^m a. m., 98.0° F.; 12^h 45^m p. m., 97.6° F.; 3^h 15^m p. m., 97.9° F.; 6^h 15^m p. m., 98.2° F. The measurements of the metabolism for the two 3-hour periods of standing and lying awake and the intermediate period are given in table 44.

TABLE 25.—*Record of pulse and respiration—Metabolism experiment No. 139.*

Date and time	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Jan. 30. A. M.			1906. Jan. 30. P. M.			1906. Jan. 30. P. M.		
10^h 40^m	..	26	12^h 25^m	68	..	3^h 25^m	54	..
10 46	56?	..	2 25	..	18	3 58	62	..
10 58	..	17	2 30	57	..	5 04	63	20
P. M.			2 44	..	16	5 52	..	17
12^h 22^m	..	18	3 20	..	20	5 55	60	..

METABOLISM EXPERIMENT No. 140.

Subject, A. H. M., January 31, 1906. (Same subject as in experiment No. 137.)

The subject entered the chamber at $8^h 15^m$ a. m., dressed in sweater, heavy underwear, trousers, and shoes as in the two previous experiments. He sat in an ordinary chair until the beginning of the experiment, which was at $9^h 45^m$ a. m. Immediately after the experiment began he rolled over from the chair into the bed, covered himself with a double blanket and then lay awake until $12^h 45^m$ p. m. In this, as in preceding experiments, the subject used the push-button to indicate that he was awake. After the conclusion of the morning period the subject got up, went to the food aperture, and placed in it the clinical thermometer, and then sat in the chair for 3 hours. He was drowsy in the morning, but did not sleep. He said he was very quiet until the period was nearly over and then turned over somewhat. He was less drowsy while sitting up, studying fully half the time.

The pulse and respiration were recorded by means of the pneumograph and are given in table 26. The body temperatures as measured sublingually by means of the clinical thermometer were as follows: $9^h 45^m$ a. m., 98.5° F.; $12^h 45^m$ p. m., 97.9° F.; $3^h 45^m$ p. m., 97.9° F. The metabolism measurements for the two 3-hour periods are given in table 44.

TABLE 26.—*Record of pulse and respiration—Metabolism experiment No. 140.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906.			1906.			1906.		
Jan. 31.			Jan. 31.			Jan. 31.		
A. M.			A. M.			P. M.		
$9^h 18^m$	..	22	$11^h 57^m$	54	19	$2^h 31^m$	57	..
9 21	60	..	P. M.			3 02	..	21
10 16	..	19	$1^h 48^m$	..	21	3 08	56	..
10 22	49	..	1 54	58	..	3 25	..	17
10 39	56	17	2 07	..	18	3 28	55	..
10 50	..	17	2 21	58	..	3 32	61	..
11 27	58	17	2 27	..	19			

The carbon-dioxide excretion per hour for the period when the subject was lying awake was 24.7 grams, and for sitting, 27.5 grams or 10.2 per cent less when he was lying awake. Like comparison of the amounts of oxygen absorbed shows 23.7 per cent less while lying awake. The water vaporized was 6 per cent higher during the period of lying awake than during sitting, which is in conformity with the fact that the water vaporized during sleep, when the subject is lying covered in bed, is sometimes higher than when he is sitting up. The activity for the period of lying awake was undoubtedly less than that which would be considered normal under such conditions.

METABOLISM EXPERIMENT No. 141.

Subject, A. H. M., February 14, 1906. (Same subject as in experiment No. 137.)

The subject entered the respiration chamber at about $7^h\ 30^m$ a. m. without breakfast and was weighed at $7^h\ 36^m$ a. m. The experiment began at 9 a. m. and continued for 8 hours. No fóod was eaten, as this experiment was planned for the study of the metabolism during the first hours of fast and the subject had not eaten since supper the night before, when he ate a dish of beans, 2 slices of graham bread with a small quantity of peanut butter, a dish of oatmeal, and a glass of milk. The subject passed 239 grams of urine at about 12 noon, and 162 grams at $5^h\ 25^m$ p. m. after leaving the chamber. He did not drink any water. A minimum of activity was sought and consequently the subject was fairly quiet throughout the experiment. This experiment is introduced here for comparison with a following experiment in which the conditions were the same except that a special series of muscular movements was introduced.

The pulse- and respiration-rates were taken by means of the pneumograph. The results are given in table 27. The body-temperature was taken in the rectum by means of the electrical-resistance thermometer. The records for each 2 hours were as follows: 9 a. m., 36.42° C.; 11 a. m., 36.50° C.; 1 p. m., 36.43° C.; 3 p. m., 36.22° C.; 5 p. m., 36.17° C. The measurements of the metabolism during the four 2-hour periods are given in table 44.

TABLE 27.—*Record of pulse and respiration—Metabolism experiment No. 141.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906.			1906.			1906.		
Feb. 14.			Feb. 14.			Feb. 14.		
A. M.			P. M.			P. M.		
$9^h\ 06^m$	..	27	$1^h\ 54^m$	37	..	$3^h\ 40^m$	42	..
9 45	..	23	1 58	39	..	4 16	41	..
P. M.			2 31	39	16	4 21	..	20
$12^h\ 17^m$	41	21	2 42	37	..	4 35	45	..
12 21	..	18	2 46	36	19	4 38	37	..
12 24	..	19	2 52	41	..	4 51	38	..
12 26	..	16	3 27	42	..	4 59	..	20
1 40	..	22	3 33	42	..			

METABOLISM EXPERIMENT No. 142.

Subject, A. H. M., March 26, 1906. (Same subject as in experiment No. 137.)

This experiment, as well as experiments Nos. 148 and 151, was designed to study the increase in metabolism required by the muscular activity incidental to rising from the chair, going to the food aperture, opening it and inserting an article (a urine jar), closing the food aperture, opening it again, removing the urine jar, closing the food aperture, and then resuming the position in the chair, a series of movements of hourly occurrence in the routine of most experiments with the respiration calorimeter. The subject in each of these experiments was

without food from the day before; in this particular case the subject ate no supper the night before and no food was eaten during the experiment.

The subject entered the respiration chamber at 7^h 30^m a. m. without breakfast and was weighed at 7^h 35^m a. m. He went through the series of movements outlined above every 5 minutes during the preliminary period and 10 seconds after the beginning of the experiment at 8^h 35^m a. m. he began the regular series for the experiment. The average length of time required for this series of movements was found to be 18.75 seconds. The experiment lasted 8 hours, and every 5 minutes during this time the subject went through the above series of movements, resting between. The subject passed 160 grams of urine at 12^h 40^m p. m. and 94 grams at 4^h 50^m p. m., after the experiment. The experiment was finished at 4^h 35^m p. m. He drank no water. The subject said that he did not feel drowsy, and although he was somewhat hungry, he felt no discomfort. He said he hurried somewhat during the operations and that the constant rising and sitting did not tire him. He read most of the time when at rest.

The pulse and respiration and body-temperature were measured as in experiment No. 141, the records for the pulse and respiration being given in table 28. The records of the body-temperature were as follows: 8^h 35^m a. m., 36.84° C.; 10^h 35^m a. m., 36.80° C.; 12^h 35^m p. m., 36.79° C.; 2^h 35^m p. m., 36.80° C.; 4^h 35^m p. m., 36.82° C. The measurements of the metabolism during this experiment are given in table 44.

TABLE 28.—*Record of pulse and respiration—Metabolism experiment No. 142.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Mar. 26. A. M.			1906. Mar. 26. A. M.			1906. Mar. 26. P. M.		
7^h 14^m	75	..	10^h 35^m	59	18	1^h 04^m	61	..
7 56	60	21	10 38	59	17	1 08	57	15
8 11	64	..	10 43	59	..	1 13	58	..
8 14	69	18	10 48	..	17	1 18	..	17
8 21	70	16	10 52	64	..	1 23	55	..
8 25	62	..	10 57	55	17	1 28	54	16
8 29	58	15	11 09	..	19	1 34	63	16
8 33	60	19	11 13	58	..	1 39	61	..
8 38	58	..	11 17	..	19	1 44	64	17
8 40	63	..	11 23	59	..	1 49	64	17
8 42	59	19	11 29	56	19	2 30	58	..
8 48	58	15	11 33	57	25	2 43	58	18
8 52	60	15	11 38	59	..	3 16	55	..
8 58	60	17	11 43	56	22	3 23	56	18
9 04	60	..	11 47	57	..	3 28	56	..
9 08	58	18	11 53	..	18	3 32	58	19
9 13	62	17	11 59	52	..	3 38	57	18
9 19	62	19	P. M.			3 45	54	16
9 23	62	17	12^h 03^m	58	16	3 50	55	..
9 28	58	24	12 08	61	..	3 54	..	18
9 33	57	22	12 13	..	19	3 57	50	..
9 38	56	17	12 18	57	..	3 59	56	16
9 43	58	19	12 23	63	15	4 04	53	20
9 47	58	19	12 28	58	15	4 08	59	20
9 54	61	19	12 31	59	..	4 12	55	..
9 58	62	17	12 39	..	21	4 14	58	..
10 03	57	16	12 43	59	..	4 18	56	..
10 08	56	16	12 48	61	18	4 21	..	18
10 13	59	18	12 53	60	18	4 26	59	18
10 33	59	..	12 59	60	..	4 33	59	20

METABOLISM EXPERIMENT No. 143.

Subject, A. H. M., April 2, 1906. (Same subject as in experiment No. 137.)

The subject entered the respiration calorimeter at $7^h 45^m$ a. m. and was weighed at $7^h 48^m$ a. m. He began eating at $8^h 26^m$ a. m. and finished at $8^h 53^m$ a. m., during which time he ate 1121 grams of bananas and 86 grams of sugar. The first period of the experiment began at $8^h 57^m$ a. m., the experiment continuing for five 2-hour periods and ending at $6^h 57^m$ p. m. During the last 2 hours the subject stood still, without leaning against a support. Previous to this he sat in the chair and read about half the time, being idle the rest of the time. The subject urinated during the experiment at 1 p. m. and passed 229 grams of urine. At $7^h 10^m$ p. m., after the experiment ended, he passed 139 grams of urine. He did not drink any water. He said it was a relief to stand after sitting still so long, but he soon tired of standing, as his back began to ache.

The observation on the metabolism during standing as compared with sitting was incidental to an experiment on the influence of the ingestion of food on metabolism. The results of the main portion of this experiment will therefore be published later in connection with a general discussion of the influence of the ingestion of food on metabolism.

The pulse, respiration, and body-temperature were determined as in experiment No. 141. The pulse and respiration records for the two periods are given in table 29. The body-temperature records were as follows: $2^h 57^m$ p. m., 36.46° C.; $4^h 57^m$ p. m., 36.32° C.; $6^h 57^m$ p. m., 36.05° C. The metabolism measurements for the last two periods are given in table 44.

TABLE 29.—*Record of pulse and respiration—Metabolism experiment No. 143.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Apr. 2 P. M.			1906. Apr. 2. P. M.			1906. Apr. 2. P. M.		
$2^h 55^m$	61	20	$4^h 11^m$	70	..	$5^h 30^m$	69	..
3 03	61	19	4 14	..	18	5 49	..	23
3 09	..	24	4 21	62	..	5 51	..	21
3 13	60	..	4 26	..	18	5 54	62	..
3 22	60	18	4 29	..	22	5 57	..	23
3 29	..	17	4 31	75	21	6 01	..	25
3 33	..	18	4 32	69	..	6 24	64	..
3 39	58	..	4 35	62	21	6 31	58	17
3 43	..	20	4 44	59	..	6 36	56	18
3 48	59	18	4 47	59	..	6 46	58	16
3 50	..	21	4 51	54	..	6 51	56	..
3 57	59	..	4 57	52	..	6 53	62	..
4 05	..	22	5 00	54	..	6 56	..	22
4 08	57	21	5 02	66	..	6 59	[1] 57	..
4 10	65	..						

[1] Wrist count after experiment.

METABOLISM EXPERIMENT No. 144.

Subject, A. H. M., April 5, 1906. (Same subject as in experiment No. 137.)

The subject entered the respiration chamber at 7^h 30^m a. m. and was weighed at 7^h 48^m a. m. The beginning of the first period was at 8^h 30^m a. m. and immediately afterwards the subject drank slowly 345 grams of cream, mixed with 246 c. c. of water. The experiment continued for five 2-hour periods and ended at 6^h 30^m p. m. During the last 2 hours the subject stood in the same manner as in the preceding experiment, and this period is here reported with the 2 hours preceding when the subject was sitting still. During both periods he was reading part of the time. At 4^h 32^m p. m. the subject passed 264 grams of urine. He drank no more water after that which was added to the cream. The subject said that the cream tasted a little sour (there had been 6 c. c. of limewater added to it). He felt no bad effects and was in no way inconvenienced by the amount. The data for the main portion of the experiment are reserved for a subsequent discussion.

The body-temperature, pulse, and respiration were determined as in experiment No. 141. The records of the pulse and respiration are given in table 30, and the body-temperature records were as follows: 2^h 30^m p. m., 36.25° C.; 4^h 30^m p. m., 36.25° C.; 6^h 30^m p. m., 36.39° C. The results for the last two periods in which the metabolism during sitting can be compared with the metabolism during standing are given in table 44.

TABLE 30.—*Record of pulse and respiration—Metabolism experiment No. 144.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Apr. 5. P. M.			1906. Apr. 5. P. M.			1906. Apr. 5. P. M.		
2^h 31^m	62	20	3^h 54^m	..	19	5^h 04^m	62	21
2 34	58	..	3 55	..	17	5 06	66	..
2 36	56	..	3 59	56	..	5 24	71	19
2 47	..	22	4 04	61	18	5 36	65	..
2 51	61	..	4 20	67	17	5 41	67	..
3 04	..	17	4 22	63	..	5 56	68	..
3 07	59	20	4 24	58	..	6 07	66	19
3 20	..	20	4 26	69	..	6 15	..	24
3 25	61	..	4 27	65	..	6 20	65	..
3 38	59	19	4 46	61	..	6 25	67	..
3 53	..	21						

METABOLISM EXPERIMENT No. 145.

Subject, H. A., November 14–15, 1905. Age, 18 years 10 months; height, 170 cm.; weight without clothing, 64.1 kilos.

The subject, a student, entered the respiration chamber in the early afternoon of November 14; the experiment began at 3 p. m. and continued for ten 2-hour periods. Immediately after the beginning of the first period, the chair, subject, bed-clothing, and other articles were weighed as described in previous experiments. After the weighing was finished the subject removed the chair from the suspension rod, put up the table, seated himself in the chair, and remained quiet until $4^h 54^m$ p. m., when he got up to urinate. At $5^h 58^m$ p. m. he took the material for his supper from the food aperture and ate 60 grams of prepared cereal and 245 grams of cream. He finished eating at $6^h 14^m$ p. m., at which time he placed the remainder of the food in the food aperture and then sat down. At $6^h 38^m$ p. m. he rose and examined the chamber connections of the rectal thermometer and then sat down. The evening, except that he stood up and sat down at $8^h 24^m$ p. m., was spent in reading until $10^h 10^m$ p. m., at which time he took down the table, stood up, and then arranged the bed. At $10^h 16^m$ p. m. he lay down and remained quiet until after 11 p. m., when he hung up the curtain and retired.

At 7 a. m., November 15, the subject was awakened, rose and passed urine, and then put up the bed. He had had trouble in adjusting the bed and so went to the food aperture to get some wire. The weighings of the chair, subject, and bedding were then made as usual. The subject then took down the chair, dressed, went to the food aperture several times, and finally put up the table for reading and sat down. He remained quiet until $8^h 14^m$ a. m., at which time he got up and went to the food aperture. After returning from the food aperture he took down the table, arranged the bed, and lay down and remained quiet until the end of the experiment, which was at 11 a. m.

This subject had been in the chamber in a previous experiment, the results of which are reported elsewhere.[1]

The pulse and respiration were taken by means of the pneumograph and the body-temperature by means of the electrical-resistance thermometer, and the results are given in table 31. Unfortunately, the pneumograph became displaced in the early morning of November 15, and records could not be secured after $4^h 27^m$ a. m. The body-temperatures in the rectum every 2 hours were as follows:

November 14—3 p. m., 37.23° C.; 5 p. m., 37.15° C.; 7 p. m., 37.37° C.; 9 p. m., 37.21° C.; 11 p. m., 37.02° C.; November 15—1 a. m., 37.23° C.; 3 a. m., 37.39° C.; 5 a. m., 37.41° C.; 7 a. m., 37.26° C.; 9 a. m., 37.02° C.; 11 a. m., 37.18° C. For some unexplainable reason the body-temperatures during the night were higher than would normally be expected with this

[1] Carpenter and Benedict, Am. Journ. Physiol., 1909, **24**.

subject. The water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat produced and eliminated are given in table 44 for the 2-hour periods from 3 p. m., November 14, to 11 a. m., November 15.

TABLE 31.—*Record of pulse and respiration—Metabolism experiment No. 145.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1905. Nov. 14. P. M.			1905. Nov. 15. A. M.			1905. Nov. 15. A. M.		
$2^h\ 31^m$	80	16	$12^h\ 21^m$	78	..	$2^h\ 45^m$	71	18
3 51	85	15	12 31	..	12	2 51	..	14
4 55	55	17	12 51	67	18	3 26	..	15
5 26	..	19	1 51	68	..	3 30	..	14
6 30	70	..	1 55	..	13	3 45	..	17
7 54	68	18	1 58	..	18	3 50	..	14
8 38	..	16	2 22	63	..	3 54	67	..
8 42	78	..	2 26	..	15	4 23	67	..
9 13	71	15	2 29	..	15	4 27	..	13
11 51	..	13						

METABOLISM EXPERIMENT No. 146.

Subject, D. W., January 14, 1906. Age, 22 years 2 months; height, 180 cm.; weight without clothing, 75.6 kilos.

The experiment here reported is a continuation of a 4-day experiment in the respiration calorimeter in which the subject (a student) fasted[1] 2 days and then for the 2 succeeding days was given a light diet. The results of the last 2 days will be published later. On the day from which the data here reported are taken, the subject was given a heavy diet, but was unable to complete the experiment. The subject had slept the night before in the respiration chamber and rose at 7 a. m., at which time the measurements here reported began.

The subject passed 184 grams of urine when he rose, then dressed, and suspended the weighing chair. The chair, subject, and bed-clothing were afterwards weighed in succession as already described. When this operation was finished and he had taken down the chair, he adjusted the bed, put up the table, and then sat down until $7^h\ 34^m$ a. m., when he rose from the chair and went to the food aperture to get his breakfast. At $7^h\ 38^m$ a. m. he went to the food aperture again to get a knife. At $7^h\ 46^m$ a. m. and $7^h\ 57^m$ a. m. he went to the food aperture for other articles. He began his breakfast at $7^h\ 44^m$ a. m. and finished at $8^h\ 04^m$ a. m., having eaten 195 grams of bread, 47 grams of butter, 844 grams of milk, and 200 grams of coffee. At $8^h\ 14^m$ a. m. he removed the rectal thermometer and placed it in the food aperture, and at $8^h\ 20^m$ a. m. he defecated. The amount of feces was 104 grams. He again opened the food aperture at $8^h\ 26^m$ a. m. to get the rectal thermometer, inserted it in the rectum, and then sat down. At $9^h\ 12^m$ a. m. he opened the food aperture several times in sending urine jars out from the chamber and

[1] Benedict, Carnegie Institution of Washington Publication No. 77, 1907.

procuring a bottle of water. At $9^h\ 22^m$ a. m. the subject took down the table, arranged the bed, lay down, and was asleep at $9^h\ 36^m$ a. m. He awoke at $12^h\ 36^m$ p. m. At $1^h\ 04^m$ p. m. he rose, urinated, and folded the bed against the wall. He then went to the food aperture for his dinner, and from $1^h\ 16^m$ p. m. to 2 p. m. he was eating, although he stopped for a few minutes at $1^h\ 48^m$ p. m. At $2^h\ 18^m$ p. m. he lay down again, but was very restless, and nausea necessitated his being taken out of the chamber. The observations from 7 a. m. to 1 p. m. only are here reported.

The pneumograph was used for recording the pulse- and respiration-rates and the electrical-resistance thermometer for obtaining the rectal temperature. The measurements were taken in 2-hour periods, and the records for pulse and respiration are given in table 32. The records for body-temperature were as follows: 7 a. m., 36.67° C.; 9 a. m., 37.22° C.; 11 a. m., 37.22° C.; 1 p. m., 37.09° C. The factors of metabolism by 2-hour periods for the time from 7 a. m. until 1 p. m. are given in table 44.

TABLE 32.—*Record of pulse and respiration—Metabolism experiment No. 146.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Jan. 14.			1906. Jan. 14.			1906. Jan. 14.		
A. M.			A. M.			P. M.		
$7^h\ 28^m$	..	20	$11^h\ 11^m$	78	..	$12^h\ 35^m$	..	14
7 42	..	17	11 24	79	..	1 52	94	..
8 45	.	21	11 41	..	19	2 08	..	18
9 30	80	..	P. M.			2 34	106	..
10 11	77	18	$12^h\ 08^m$	75	17	2 39	98	..
10 32	79	19	12 23	76	..	2 54	100	..

METABOLISM EXPERIMENT No. 147.

Subject, A. L. L., February 9, 1906. Age, 24 years 9 months; height, 166 cm.; weight without clothing, 67.5 kilos.

The subject was a student in Wesleyan University and the experiment was made as a part of a special study already mentioned of the metabolism during the early hours of fasting. The results are presented here for comparison with the results in a later experiment with the same subject in which he performed a particular series of movements common to experiments in the respiration calorimeter.

The subject entered the respiration chamber at $7^h\ 30^m$ a. m., having eaten no food since the evening before when a light supper consisting of 1½ bowlfuls of bean soup was eaten. He was weighed at $7^h\ 53^m$ a. m. and the first period began at 9 a. m. The experiment continued for 8 hours, measurements being made in 2-hour periods. The subject remained very quiet, sitting in the chair reading during the whole experiment. He did not urinate nor drink water during the whole experiment. The subject had previously been in the chamber a number of times.

The body-temperature was taken with the electrical-resistance thermometer and the pulse and respiration with a pneumograph. The records for the pulse and respiration are given in table 33. The records of the body-temperature were as follows: 9 a. m., 36.88° C.; 11 a. m., 36.78° C.; 1 p. m., 36.69° C.; 3 p. m., 36.71° C.; 5 p. m., 36.88° C. The measurements of the metabolism in the four 2-hour periods are given in table 44.

TABLE 33.—*Record of pulse and respiration—Metabolism experiment No. 147.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Feb. 9. A. M.			1906. Feb. 9. A. M.			1906. Feb. 9. P. M.		
$8^h\ 32^m$	..	18	$11^h\ 13^m$	..	17	$1^h\ 48^m$	..	17
8 45	56	..	11 37	..	17	1 49	..	20
8 53	56	..	11 47	58	..	1 56	48	..
9 09	..	18	P. M.			2 10	50?	19
9 15	58	..	$12^h\ 01^m$	58	19	2 34	51?	18
9 24	58	18	12 23	..	18	2 58	56?	20
9 42	58	18	12 28	57	..	3 11	61?	18
10 03	..	19	12 46	..	17	3 48	..	18
10 07	60	..	1 03	..	19	4 09	54?	19
10 37	57	20	1 08	50?	..	4 29	..	18
10 52	..	18	1 14	49?	..	4 33	..	19
10 57	57	..	1 25	..	18	4 57	..	19
11 10	55	..	1 28	47?	19	4 59	..	22

METABOLISM EXPERIMENT No. 148.

Subject, A. L. L., March 20, 1906. (Same subject as in experiment No. 147.)

The subject entered the calorimeter chamber at about $7^h\ 30^m$ a. m., without breakfast, and took no food during the experiment. For supper the night before he had eaten a bowlful of oatmeal with milk and sugar, 2 slices of bread, and a cup of cocoa. The subject remained seated in the chair until 15 minutes before the experiment began. He then rose from the chair and went through the operation of opening and closing the food aperture, as described in experiment No. 142. (See p. 61.) The first period began at $9^h\ 10^m$ a. m., and a few moments later the subject resumed the operation, carrying it out every 5 minutes during the whole experiment. The average time taken for the series of movements was 29 seconds. The experiment ended at $5^h\ 10^m$ p. m., and measurements were made in four 2-hour periods. The subject did not urinate or drink during the experiment. At $5^h\ 25^m$ p. m., after the experiment was ended, 349 grams of urine were passed. After coming out of the chamber he said that getting up and down so often was somewhat tiresome. He was not at all thirsty during the day, but was hungry.

The pulse and respiration were taken by means of the pneumograph and the records are given in table 34. The body temperature records were made by the rectal thermometer and were as follows: $9^h\ 10^m$ a. m., 36.86° C.; $11^h\ 10^m$ a. m., 36.76° C.; $1^h\ 10^m$ p. m., 36.67° C.; $3^h\ 10^m$ p. m., 36.63° C.; $5^h\ 10^m$ p. m., 36.67° C. The measurements of the metabolism are given in table 44.

TABLE 34.—*Record of pulse and respiration—Metabolism experiment No. 148.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Mar. 20. A. M.			1906. Mar. 20. A. M.			1906. Mar. 20. P. M.		
7h 27m	85	..	11h 17m	..	18	2h 16m	54	18
7 57	64	..	11 23	56	..	2 18	55	19
8 02	60	..	11 28	60	18	2 20	57	18
8 03	68	..	11 33	..	18	2 22	53	18
8 04	62	..	11 42	55	19	2 25	58	20
8 07	55	..	11 47	56	..	2 29	61	21
8 08	62	..	11 53	..	17	2 32	59	..
8 21	63	20	11 57	..	19	2 39	57	21
8 29	65	..	P. M.			2 43	53	19
8 33	68	..	12h 02m	57	..	2 47	54	20
8 38	..	19	12 13	58	18	2 53	52	18
8 48	55	19	12 17	62	..	2 57	57	18
8 52	..	17	12 19	59	19	3 04	57	19
8 59	58	..	12 23	..	18	3 08	53	18
9 02	..	20	12 30	55	..	3 12	55	20
9 07	58	20	12 39	56	19	3 15	58	20
9 16	..	21	12 43	59	20	3 18	56	..
9 22	60	..	12 48	62	17	3 23	54	18
9 27	..	23	12 54	61	20	3 27	54	16
9 33	58	22	12 58	54	19	3 33	54	19
9 40	..	24	1 01	56	..	3 37	52	18
9 42	58	21	1 07	60	19	3 42	54	22
9 46	57	..	1 15	..	19	3 47	52	..
9 53	57	22	1 20	63	..	3 53	54	17
10 03	..	22	1 24	57	..	3 58	56	21
10 14	54	20	1 29	58	19	4 06	..	19
10 23	..	20	1 33	58	..	4 13	52	19
10 28	59	..	1 40	..	18	4 18	..	20
10 34	56	19	1 48	..	19	4 28	57	19
10 41	..	21	1 52	56	..	4 39	55	18
10 42	..	19	1 54	59	..	4 45	53	..
10 44	..	17	1 58	53	18	4 49	60	19
10 58	55	18	2 02	58	19	4 56	..	18
11 04	56	..	2 08	57	17	5 03	53	20
11 09	..	17	2 11	57	19	5 07	57	16
11 13	..	18	2 13	59	19			

METABOLISM EXPERIMENT No. 149.

Subject, A. L. L., April 3, 1906. (Same subject as in experiment No. 147.)

The subject entered the respiration chamber at 7^h 35^m a. m. without breakfast. He had a light supper the evening before, consisting of a bowlful of oatmeal with milk and sugar, and a cup of cocoa. He was weighed immediately and then remained quietly seated in the chair until the beginning of the first period, which was at 8^h 40^m a. m. The experiment continued for five 2-hour periods and no food was eaten. In the first and second periods, the subject continued sitting quietly in the chair; during the third and fourth periods, he was chewing gum; in the fifth period he was standing quietly without leaning. At 4^h 42^m p. m., he passed 660 grams of urine and at 7 p. m., after the experiment ended, he passed 46 grams of urine. He drank no water during the experiment. The subject's comments were that he was not sleepy during the experiment, and that he was tired of standing during the last half hour—too tired to study.

This experiment is one of a series made to study the work of digestion, and will therefore be given in greater detail and completeness and as part of a

series of comparisons in a later publication. The results for the first, second, and fifth periods are here reported as a comparison between the metabolism while sitting and the metabolism while standing.

The pulse, respiration, and body-temperature were taken as in experiment No. 148, the pulse and respiration records being given in table 35. The body-temperature records were as follows: $8^h 40^m$ a. m., 36.69° C.; $10^h 40^m$ a. m., 36.59° C.; $12^h 40^m$ p. m., 36.65° C.; $2^h 40^m$ p. m., 36.65° C.; $4^h 40^m$ p. m., 36.65° C.; $6^h 40^m$ p. m., 37.16° C. The records of the metabolism are given in table 44.

TABLE 35.—*Record of pulse and respiration—Metabolism experiment No. 149.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Apr. 8. A. M.			1906. Apr. 8. A. M.			1906. Apr. 8. P. M.		
$7^h 27^m$	73	..	$10^h 25^m$	56	..	$12^h 20^m$	..	18
7 28	64	..	10 34	58	17	12 24	47	..
7 52	57	..	10 39	56	..	12 27	45	..
7 56	..	18	10 45	56	18	12 34	..	17
8 13	..	17	10 51	..	17	4 40	55	..
8 21	57	..	10 52	..	19	4 49	..	21
8 34	49	18	10 55	58	..	4 52	57	..
8 39	51	..	10 56	53	..	4 55	56	..
8 50	56	17	10 57	50	..	5 03	..	20
8 56	56	..	10 59	55	..	5 07	61	..
9 03	56	17	11 03	..	16	5 21	..	20
9 19	..	20	11 12	63	..	5 25	..	19
9 22	63	..	11 15	60	..	5 29	70	..
9 33	..	18	11 19	..	16	5 35	..	21
9 37	60	..	11 24	52	..	5 39	68	..
9 40	58	..	11 27	62	..	5 47	65	21
9 49	59	..	11 31	60	..	5 52	68	..
9 52	..	17	11 34	..	18	6 02	..	21
9 56	54	..	11 38	61	..	6 04	69	..
10 00	65	..	11 47	57	18	6 17	..	19
10 07	..	19	11 51	58	..	6 19	64	18
10 15	60	18	P. M.			6 21	68	..
10 19	63	18	$12^h 05^m$	..	17	6 30	64	..
10 23	60	..	12 11	59	..	6 32	67	19

METABOLISM EXPERIMENT No. 150.

Subject, H. R. D., February 10, 1906. Age, 17 years and 10 months; height, 171 cm.; weight without clothing, 57.7 kilos.

The subject was a student in Wesleyan University and this experiment was made to study the metabolism during the early hours of fasting. The results are included here for comparison with a following experiment in which the results are given for a particular series of movements common to respiration-calorimeter experiments.

The subject entered the respiration chamber at $7^h 30^m$ a. m. without having eaten any breakfast. The meal the evening before consisted of potato, 2 slices of bread, a small amount of rice pudding, and 3 glasses of milk. He was weighed at $7^h 53^m$ a. m. and then remained seated in the chair until the beginning of the first period, which was at $9^h 15^m$ a. m. The experiment continued for 8 hours and during this time the subject remained sitting quietly in the

chair, reading most of the time. During the third period he drank 432 c. c. of water. No food was eaten during the experiment. The subject passed 118 grams of urine at $1^{h}\,15^{m}$ p. m., the end of the second period. He was familiar with the apparatus, as he had served as a subject before.

The pulse, respiration, and body-temperature were taken as in experiment No. 148, the records of the pulse and respiration being given in table 36. The records of the body-temperature were as follows: $9^{h}\,15^{m}$ a. m., 36.90° C.; $11^{h}\,15^{m}$ a. m., 36.73° C.; $1^{h}\,15^{m}$ p. m., 36.73° C.; $3^{h}\,15^{m}$ p. m., 36.67° C.; $5^{h}\,15^{m}$ p. m., 36.61° C. The measurements of the metabolism were made in four 2-hour periods and are given in table 44.

TABLE 36.—*Record of pulse and respiration—Metabolism experiment No. 150.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906.			1906.			1906.		
Feb. 10.			Feb. 10.			Feb. 10.		
A. M.			A. M.			P. M.		
$8^{h}\ 45^{m}$	..	19	$11^{h}\ 48^{m}$	..	18	$2^{h}\ 03^{m}$	..	18
8 48	78	..	11 53	66	..	2 09	63	..
8 49	68	..	11 57	61	18	2 12	60	..
8 53	71	..	12 00	61	..	2 17	58	..
9 08	..	18	P. M.			3 07	57	18
9 16	69	18	$12^{h}\ 14^{m}$	61	18	3 21	62	..
9 52	..	16	12 28	59	18	3 28	..	19
9 56	67	..	12 53	64	18	3 52	59	16
10 05	69	17	1 05	65	..	3 58	..	18
10 39	..	19	1 09	62	18	4 07	59	17
10 45	59	..	1 25	57	14	4 32	..	18
10 48	57	..	1 31	62	20	4 36	60	..
10 53	57	..	1 36	..	19	4 39	59	19
10 57	57	16	1 46	58	19	5 03	58	19
11 03	..	17	1 49	..	18	5 12	59	19
11 08	59	..						

METABOLISM EXPERIMENT No. 151.

Subject, H. R. D., March 24, 1906. (Same subject as in experiment No. 150.)

The subject entered the respiration chamber at $7^{h}\,30^{m}$ a. m., having eaten no food since the noon meal of the day before. He was weighed at $7^{h}\,40^{m}$ a. m. and the first period began at $8^{h}\,40^{m}$ a. m. The subject after the beginning of the experiment repeated exactly the operations of the subjects of experiments Nos. 142 and 148 (see p. 61), in that every 5 minutes he went to the food aperture, opened it, closed it, etc., and then returned to his chair. The experiment ended at $4^{h}\,40^{m}$ p. m. The subject drank 227 c. c. of water at $3^{h}\,20^{m}$ p. m. and passed 184 grams of urine at $4^{h}\,52^{m}$ p. m., after the experiment ended. Most of the time between the operations of going to the food aperture the subject read, and he did not miss going to the food aperture at any time. The average time taken to complete the series of movements was 26.25 seconds. The subject said that while he found it difficult to be exact as to the time of the operation, he did not find the movements tiresome. He said he was not at all drowsy, but felt hungry and somewhat thirsty.

The body-temperature was measured with the rectal thermometer and the pulse- and respiration-rates were taken in the usual way with the pneumograph. The records for the pulse and respiration are given in table 37, and the body-temperatures were as follows: $8^h\ 40^m$ a. m., 36.92° C.; $10^h\ 40^m$ a. m., 36.84° C.; $12^h\ 40^m$ p. m., 36.69° C.; $2^h\ 40^m$ p. m., 36.76° C.; $4^h\ 40^m$ p. m., 36.80° C. The measurements of the metabolism are given for the four 2-hour periods in table 44.

TABLE 37.—*Record of pulse and respiration—Metabolism experiment No. 151.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Mar. 24. A. M.			1906. Mar. 24. A. M.			1906. Mar. 24. P. M.		
$7^h\ 34^m$	75	..	$11^h\ 01^m$	62	21	$1^h\ 49^m$	62	..
8 17	76	..	11 05	59	17	1 53	62	..
8 21	72	17	11 11	65	20	1 59	61	19
8 26	72	..	11 16	62	20	2 04	60	20
8 31	70	17	11 21	61	19	2 08	61	17
8 35	71	18	11 26	62	..	2 18	59	..
8 39	66	..	11 31	63	19	2 23	60	20
8 41	72	18	11 36	58	19	2 27	59	20
8 45	76	..	11 41	66	18	2 32	60	..
8 48	..	17	11 47	60	20	2 39	58	19
8 52	69	..	11 50	64	19	2 42	58	19
8 55	67	17	11 55	62	19	2 49	61	..
9 01	68	18	12 00	62	18	2 53	64	19
9 07	68	18	P. M.			2 57	..	18
9 11	69	15	$12^h\ 05^m$	60	20	3 03	58	19
9 16	66	15	12 10	61	17	3 08	59	20
9 22	68	..	12 15	58	19	3 13	61	19
9 27	66	18	12 21	67	19	3 18	59	19
9 31	75	18	12 25	65	19	3 23	63	20
9 36	68	..	12 30	65	19	3 29	57	..
9 40	67	18	12 36	67	18	3 33	59	19
9 51	67	16	12 40	63	..	3 38	60	..
9 56	66	22	12 43	65	19	3 43	60	19
10 01	64	19	12 47	..	20	3 49	60	20
10 06	64	..	12 50	64	..	3 52	59	20
10 11	65	18	12 54	61	18	3 58	59	19
10 16	62	16	12 59	59	17	4 03	57	19
10 20	60	17	1 05	..	18	4 08	56	18
10 26	63	17	1 08	58	19	4 13	61	19
10 31	68	15	1 12	60	..	4 18	59	17
10 36	62	..	1 24	64	17	4 23	61	20
10 40	61	15	1 28	64	18	4 28	59	20
10 46	55	16	1 34	62	19	4 34	65	19
10 50	58	18	1 39	59	19	4 38	62	20
10 56	59	18	1 43	63	20	4 43	59	..

METABOLISM EXPERIMENT No. 152.

Subject, H. R. D., March 31, 1906. (Same subject as in experiment No. 150.)

The subject entered the respiration chamber at $7^h\ 30^m$ a. m. and was weighed at $7^h\ 42^m$ a. m. After the apparatus was in equilibrium, he began eating bananas and sugar at $8^h\ 16^m$ a. m. and finished at $8^h\ 42^m$ a. m., having eaten 1173 grams of bananas and 103 grams of sugar. For the following 8 hours the subject sat quietly in the chair, reading most of the time. At $12^h\ 45^m$ p. m. and $4^h\ 45^m$ p. m. he passed 302 grams and 257 grams of urine, respectively. At $4^h\ 45^m$ p. m. the subject got up from his chair and for an additional 2 hours

stood in one position, not moving about and without leaning. The experiment ended at $6^h 45^m$ p. m. and at $7^h 05^m$ p. m. 28 grams of urine were passed. The subject said that he felt quite well all the time, that the large amounts of bananas and sugar caused him no discomfort, but that the standing still upright troubled him considerably. The subject drank no water during the entire experiment.

This experiment is one of a series made for the purpose of studying the problem of the cost of digestion. The period of standing was incidental, and the main portion of the experiment will therefore be presented in a later publication treating the subject of digestion as studied in a large number of experiments. The results for the last 4 hours are given in table 44 for a comparison of the metabolism under two different conditions of muscular activity.

The pulse- and respiration-rates were obtained by means of the pneumograph and the records for the two periods between $4^h 45^m$ p. m. and $6^h 45^m$ p. m. are given in table 38. The rectal body-temperature was taken with the electrical-resistance thermometer. The temperatures for each 2 hours of the periods here reported were at $2^h 45^m$ p. m., 36.86° C.; $4^h 45^m$ p. m., 36.59° C.; $6^h 45^m$ p. m., 36.84° C. The metabolism for the last 2 hours of sitting and the 2 hours of standing are given in table 44.

TABLE 38.—*Record of pulse and respiration—Metabolism experiment No. 152.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Mar. 31. P. M.			1906. Mar. 31. P. M.			1906. Mar. 31. P. M.		
$2^h 46^m$	72	19	$3^h 57^m$	72	20	$5^h 25^m$	78	18
2 51	..	20	4 01	80	20	5 34	80	19
2 56	73	..	4 06	75	20	5 39	75	..
3 00	78	19	4 10	77	18	5 45	76	19
3 04	80	17	4 14	74	20	5 50	..	21
3 08	80	19	4 18	78	18	5 54	80	..
3 14	76	20	4 30	78	18	5 59	76	21
3 18	74	19	4 40	83	19	6 10	79	23
3 24	78	21	4 45	77	19	6 15	..	21
3 27	72	18	4 51	80	21	6 22	78	20
3 32	..	19	4 57	83	20	6 31	81	21
3 36	80	19	5 02	77	20	6 36	76	..
3 42	78	21	5 08	75	18	6 40	83	22
3 45	74	19	5 15	..	19	6 44	83	21
3 51	80	19	5 20	78	19			

METABOLISM EXPERIMENT No. 153.

Subject, H. R. D., May 18, 1906. (Same subject as in experiment No. 150.)

The periods here reported were part of an experiment which began at $9^h 10^m$ a. m., May 17, and was made for the study of the problem of the ingestion of food. The subject entered the chamber at $7^h 30^m$ a. m., May 17, was weighed, and then ate 153 grams of gluten bread, and 499 grams of skim milk between $8^h 29^m$ a. m. and $9^h 08^m$ a. m. He remained seated in the chair during the

whole of the day until $9^h 10^m$ p. m., when he was weighed again, and retired. At $7^h 10^m$ a. m., May 18, the subject began a period of lying awake which lasted until the end of the experiment at $1^h 10^m$ p. m. The results in their application to the study of the work of digestion will be included in a later publication. The periods of 6 hours each are given here for a comparison of metabolism while lying asleep with that while lying awake.

The portion of the experiment here reported extends from $1^h 10^m$ a. m. until the end of the experiment at $1^h 10^m$ p. m., May 18, thus covering a period from $1^h 10^m$ a. m. to $7^h 10^m$ a. m., when the subject was asleep in bed, and a second period, $7^h 10^m$ a. m. to $1^h 10^m$ p. m., when he remained in bed but not asleep. The subject slept well during the night but sat up in bed for a moment at $2^h 30^m$ a. m. and awoke finally at $6^h 30^m$ a. m., although he was not supposed

TABLE 39.—*Record of pulse and respiration—Metabolism experiment No. 153.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906.			1906.			1906.		
May 18.			May 18.			May 18.		
A. M.			A. M.			A. M.		
1^h 06^m	60	16	7^h 47^m	65	..	11^h 10^m	60	..
1 33	57	..	8 09	..	15	11 20	..	20
1 37	..	15	8 11	..	19	11 24	68	20
2 35	..	14	8 32	56	..	11 29	72	..
2 40	54	14	8 37	60	19	11 43	..	21
3 18	58	13	9 19	69	..	11 45	72	20
3 49	56	14	9 22	..	18	11 47	70	..
4 10	..	15	9 25	..	17	P. M.		
4 40	49	..	9 33	72	..	12^h 12^m	..	19
5 24	60	15	9 36	71	18	12 14	72	19
5 27	59	15	9 40	..	18	12 17	74	..
6 30	60	..	9 50	75	..	12 33	..	19
6 35	..	15	9 53	..	18	12 36	67	19
6 50	..	15	10 27	75	..	12 38	68	..
6 54	57	..	10 33	74	18	12 51	..	17
7 04	60	15	10 46	61	18	12 55	67	..
7 26	69	16	10 48	63	..	1 01	..	19
7 29	70	..	11 05	..	18	1 05	76	..
7 44	..	18	11 08	60	19			

to be awake until $7^h 10^m$ a. m. He did not rise until called at $7^h 10^m$ a. m. He then passed 291 grams of urine and at $7^h 16^m$ a. m. he readjusted the rectal thermometer. The subject lay quietly awake till $1^h 10^m$ p. m., when he passed 199 grams of urine. The report of the subject was that he slept most of the night; that he was troubled with a slight backache, especially during the time when he was lying awake; and that he was not sleepy during the lying awake period and did not sleep any.

The pulse and respiration were taken by means of the pneumograph and the records will be found in table 39. The rectal temperature was taken by means of the electrical-resistance thermometer. Unfortunately, the thermometer did not keep its adjustment during the night and records prior to $7^h 10^m$ a. m. could be considered only as indicating changes in temperature from period to period, and not absolute body-temperatures. These changes from period to period have been used in obtaining the heat production during the

periods from $1^h\ 10^m$ a. m. to $7^h\ 10^m$ a. m. The rectal temperatures are here reported for each 2 hours after the thermometer was readjusted at $7^h\ 16^m$ a. m. The body-temperature records were as follows: $7^h\ 20^m$ a. m., 36.44° C.; $9^h\ 10^m$ a. m., 36.61° C.; $11^h\ 10^m$ a. m., 36.57° C.; $1^h\ 10^m$ p. m., 36.48° C. The metabolism was measured in 2-hour periods and the results for the portion of the experiment here reported are given in table 44.

METABOLISM EXPERIMENT No. 154.

Subject, J. H. K., April 17, 1906. Age, 54 years 2 months; height, 164 cm.; weight without clothing, 56.1 kilos.

The subject (a physician) entered the respiration chamber at $12^h\ 30^m$ p. m. and was weighed at $12^h\ 45^m$ p. m. The experiment as reported consists of three parts, the first part from 2 p. m. to 6 p. m., when the subject was on his feet all the time and either walking or standing or lifting himself as when walking; the second part, from $7^h\ 15^m$ p. m. to $9^h\ 15^m$ p. m., when he was lying asleep or quietly awake; and the third part from $9^h\ 15^m$ p. m. to $11^h\ 15^m$ p. m., when he was lying quietly awake. The measurements were in 2-hour periods. During most of the time from 2 p. m. to 6 p. m. the subject was walking a pace or two forward or backward, as the narrow confines of the chamber permitted. Occasionally he stood, and at one time he stood and went through calisthenic exercises for a few minutes. At $3^h\ 06^m$ p. m. the subject took off his coat and vest and ate 136 grams of orange, while standing still. At $5^h\ 42^m$ p. m. he put on his coat. At 6 p. m. an intermediate period began, during which the subject adjusted the bed and then sat down. A lunch consisting of 348 grams of oranges was eaten at $6^h\ 22^m$ p. m. The subject then placed the uneaten food in the food aperture, lay down upon the bed, picked up the blanket, and spread it over his feet, and was quietly reading at $6^h\ 48^m$ p. m. The second part of the experiment began at $7^h\ 15^m$ p. m., and the subject was probably asleep at this time. He remained very quiet until $8^h\ 16^m$ p. m., when he awoke. At $8^h\ 22^m$ p. m. he picked up his glasses from the floor and then removed the blanket from his feet. From that time on until the end of the experiment the subject was lying down and reading most of the time. At about $11^h\ 06^m$ p. m. the subject rose, and after picking up his glasses he lay down again. The experiment was concluded at $11^h\ 15^m$ p. m.

The subject estimated that he took about 1 step a second while walking and raised his body about 1.5 miles, and that the work done during the first portion of the experiment was not as much as he would ordinarily do at his home while walking. He reported that he slept about 1 hour during the second portion of the experiment, as noted on his watch. He was not soundly asleep all of the time, but was very quiet. This was his first experience in the chamber.

The pulse- and respiration-rates were recorded by means of the pneumograph and were as shown in table 40. During the first part of the experiment, the

rectal thermometer could not be used because it would not remain in place while the subject was walking, so the body-temperatures were taken by means of a clinical thermometer in the mouth. The buccal temperatures were as follows: 2ʰ 05ᵐ p. m., 97.95° F.; 4ʰ 05ᵐ p. m., 98.3° F.; 6 p. m., 98.3° F. At 6ʰ 20ᵐ p. m. the resistance thermometer was inserted in the rectum and records were made as usual during the remainder of the experiment. The temperatures for each 2 hours were, at 6ʰ 32ᵐ p. m., 36.92° C.; 7ʰ 15ᵐ p. m., 36.64° C.; 9ʰ 15ᵐ p. m., 36.55° C.; 11ʰ 15ᵐ p. m., 36.38° C. The results of the metabolism are given in 2-hour periods in table 44.

TABLE 40.—*Record of pulse and respiration—Metabolism experiment No. 154.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. Apr. 17. P. M.			1906. Apr. 17. P. M.			1906. Apr. 17. P. M.		
2ʰ 26ᵐ	76	..	6ʰ 29ᵐ	..	23	7ʰ 59ᵐ	..	14
2 40	72	..	6 43	70	..	8 29	..	20
3 14	..	22	6 55	70	19	8 36	68	19
3 39	74	..	7 12	61	..	9 04	67	17
3 54	75	21	7 15	64	16	9 12	68	..
4 03	..	18	7 21	62	..	9 29	65	..
4 25	..	23	7 28	..	15	10 22	..	20
5 16	69	..	7 32	65	..	10 26	60	..
5 21	78	22	7 38	..	15	10 41	..	20
5 25	73	..	7 42	65	15	10 56	..	20
5 28	78	20						

METABOLISM EXPERIMENT No. 155.

Subject, H. C. K., May 3, 1906. Age, 21 years 10 months; height, 181 cm.; weight without clothing, 73.6 kilos.

The subject, who was a student in Wesleyan University, came to the laboratory a little before 8 a. m., entered the calorimeter chamber immediately, and was weighed. He had eaten no food since the evening before, when he ate a light supper consisting of 2 glasses of milk and 3 slices of bread. The experiment began at 9ʰ 05ᵐ a. m. and ended at 5ʰ 05ᵐ p. m., the measurements being made in four 2-hour periods. The subject sat quietly in the chair during the whole of the time except at the beginning of each period, when he urinated. The amounts of urine at 9ʰ 05ᵐ a. m., 11ʰ 05ᵐ a. m., 1ʰ 05ᵐ p. m., and 3ʰ 05ᵐ p. m. were 82 grams, 111 grams, 98 grams, and 93 grams, respectively. The subject passed 96 grams of urine after the experiment ended at 5ʰ 05ᵐ p. m. He ate no food and drank no water during the experiment. He reported that the chair he was sitting in was not very comfortable, that he read about one-third of the time, and found it tiresome sitting still. He had been a subject before in a 2-days' fast. This experiment was one of a series planned for the study of metabolism during the early hours of fast. It is introduced here for comparison with following experiments with this subject in which he was lying asleep and lying awake.

The pneumograph was used for obtaining the pulse and respiration, which are given in table 41. The electrical-resistance thermometer was used for measuring the body-temperature and the records are as follows: $9^h 05^m$ a. m., 36.51° C.; $11^h 05^m$ a. m., 36.48° C.; $1^h 05^m$ p. m., 36.61° C.; $3^h 05^m$ p. m., 36.55° C.; $5^h 05^m$ p. m., 36.80° C. The results of the metabolism are recorded in table 44.

TABLE 41.—*Record of pulse and respiration—Metabolism experiment No. 155.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. May 3.			1906. May 3.			1906. May 3.		
A. M.			P. M.			P. M.		
$7^h 37^m$	82	..	$2^h 20^m$	..	19	$3^h 40^m$	52	..
7 38	78	..	2 24	47	19	3 44	..	20
8 22	55	18	2 27	51	..	3 49	54	..
8 28	60	..	2 30	..	18	3 53	..	19
8 57	54	..	2 34	48	19	3 58	53	..
9 21	50	17	2 39	46	19	4 02	..	20
9 28	54	..	2 46	..	20	4 07	50	..
9 35	..	18	2 50	48	19	4 11	..	19
9 51	51	..	2 54	48	18	4 16	52	..
10 23	51	18	2 58	50	18	4 20	..	20
10 43	52	18	3 04	47	19	4 24	56	..
11 21	47	16	3 07	..	22	4 28	..	18
11 55	46	..	3 10	48	..	4 32	50	..
12 00	..	16	3 15	..	20	4 36	..	16
P. M.			3 19	48	..	4 40	56	..
$12^h 21^m$	46	15	3 22	..	19	4 47	56	19
12 43	49	16	3 26	48	..	4 51	..	17
1 20	47	..	3 30	..	19	4 55	63	..
1 50	46	19	3 33	48	..	4 58	..	19
2 04	48	..	3 37	..	21	5 03	57	22
2 08	..	19						

METABOLISM EXPERIMENT No. 156.

Subject, H. C. K., May 16, 1906. (Same subject as in experiment No. 155.)

The subject had entered the calorimeter the day before and after being weighed had eaten between $8^h 16^m$ a. m. and $8^h 50^m$ a. m., 100 grams of plasmon, 47 grams of plasmon graham biscuit, and 439 grams of skim milk. He had remained in the chamber the whole day, sitting quietly in an arm-chair, and had urinated at $9^h 10^m$ p. m. and retired at $9^h 44^m$ p. m. During the night he slept with his clothes on and with a blanket drawn up over him, but during the morning from $7^h 10^m$ a. m. to $1^h 10^m$ p. m., he lay awake. The blanket was removed between 5 a. m. and 7 a. m., and was not used again during the remainder of the experiment. The subject passed 348 grams of urine at $7^h 10^m$ a. m. and 295 grams after the experiment ended, at $1^h 10^m$ p. m. He drank no water during the periods here reported. The subject said that he did not sleep very well during the night, was rather restless, that the pneumograph felt uncomfortable, especially around his back, and that when he was awake during the day he could not lie still, and consequently was somewhat restless. This experiment, and experiment No. 157 were planned for

the study of the effect upon metabolism of the ingestion of food, and the details and results for the first portion are therefore reserved for a later publication. The periods here given are from 1h 10m a. m. to 7h 10m a. m., May 16, when the subject was in bed asleep, and from 7h 10m a. m. to 1h 10m p. m., when he was lying in bed awake.

The pulse and respiration were counted from the indications on the pneumograph and the records are given in table 42. The body-temperature was taken by means of the electrical rectal thermometer. The records are given herewith and are as follows: 1h 10m a. m., 36.50° C.; 3h 10m a. m., 36.63° C.; 5h 10m a. m., 36.69° C.; 7h 10m a. m., 36.69° C.; 9h 10m a. m., 36.68° C.; 11h 10m a. m., 36.62° C.; 1h 10m p. m., 36.66° C. The results of the metabolism for the periods reported here are given in table 44.

TABLE 42.—*Record of pulse and respiration—Metabolism experiment No. 156.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. May 16. A. M.			1906. May 16. A. M.			1906. May 16. A. M.		
1h 27m	..	16	6h 56m	49	..	10h 21m	55	..
1 33	45	..	7 05	59	..	10 30	..	20
1 47	..	16	7 08	..	17	10 33	54	19
1 51	47	..	7 23	49	17	10 37	54	..
2 18	43?	..	7 40	45	15	10 59	56	..
2 24	..	15	8 07	49	16	11 03	..	17
2 36	44?	..	8 23	51	..	11 17	..	17
2 41	..	15	8 29	..	15	11 22	51	..
3 02	47	15	8 32	..	15	11 34	..	17
3 31	48	14	8 46	48	..	11 46	58	..
3 48	49	15	8 52	..	15	P. M.		
4 07	46	..	9 08	54	16	12h 07m	57	..
4 11	..	16	9 26	..	18	12 11	53	..
4 36	47	17	9 30	..	19	12 14	..	18
4 55	49	..	9 34	57	..	12 16	..	19
5 02	..	16	9 39	..	19	12 27	56	..
5 34	47	..	9 46	53	..	12 30	58	19
5 39	..	15	9 49	56	18	12 33	..	19
5 58	51	17	9 55	..	19	12 42	55	..
6 20	47	16	9 58	56	19	12 53	55	..
6 35	46	15	10 15	..	18	1 04	58	21?
6 53	51	16	10 18	55	..			

METABOLISM EXPERIMENT No. 157.

Subject, H. C. K., May 23, 1906. (Same subject as in experiment No. 155.)

The subject entered the respiration chamber the day before. Shortly after entering he was weighed at 7h 54m a. m., and between 8h 40m a. m. and 9h 25m a. m. he ate 38 grams of gluten bread and 1009 grams of skim milk. The rest of the day he remained seated quietly in the chair until 9h 30m p. m., when he urinated and went to bed, after making the customary preparations for the night. He slept during the night with his clothes on and with a blanket drawn up over him, and the next morning instead of getting up, he lay in bed awake and remained quiet until 1h 30m p. m. The blanket was removed at 6h 15m a. m. and was not used again during the remainder of the experiment. The subject passed 423 grams of urine at 7h 30m a. m. and 311 grams

after the experiment ended at 1^h 30^m p. m. He drank no water during the periods here reported. The results for the first portion of the experiment will be reported elsewhere; the measurements here given are for the time between 1^h 30^m a. m. and 7^h 30^m a. m., May 23, and between 7^h 30^m a. m. and 1^h 30^m p. m. The subject reported that he slept fairly well during the night and was not troubled at any time by the pneumograph. He said he did not sleep any after 7^h 30^m a. m., but that he had a slight backache and was chilly about the ankles.

The pulse and respiration were taken as usual and are given in table 43. The body-temperature was measured by means of the electrical rectal thermometer and was as follows. 1^h 30^m a. m., 36.18° C.; 3^h 30^m a. m., 36.10° C.; 5^h 30^m a. m., 36.46° C.; 7^h 30^m a. m., 36.53° C.; 9^h 30^m a. m., 36.63° C.; 11^h 30^m a. m., 36.61° C.; 1^h 30^m p. m., 36.66° C. The metabolism for 6 hours while lying asleep and 6 hours while lying awake is given in table 44. The measurements were in 2-hour periods.

TABLE 43.—*Record of pulse and respiration—Metabolism experiment No. 157.*

Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.	Date and time.	Pulse-rate per minute.	Respiration-rate per minute.
1906. May 23. A. M.			1906. May 23. A. M.			1906. May 23. A. M.		
1^h 45^m	38	14	8^h 16^m	47	..	10^h 59^m	..	17
2 26	40	14	8 27	50	16	11 03	53	..
3 17	42	15	8 50	49	15	11 22	51	..
4 07	49	17	9 14	..	17	11 35	..	17
4 37	44	17	9 17	58	..	11 38	52	..
5 00	49	15	9 34	57	..	11 53	61	19
5 13	46	16	9 43	..	20	P. M.		
5 42	43	15	9 47	54	18?	12^h 11^m	54	..
6 20	47	15	10 02	57	..	12 35	53	18
6 49	50	16	10 05	..	20	12 45	55	..
7 05	47	14	10 18	..	20	12 50	..	18
7 39	56	..	10 21	54	..	1 02	55	18
7 42	..	16	10 35	53	..	1 22	56	..
7 58	44	16	10 46	57	19	1 24	62	..
8 13	..	15	10 50	60	..			

DRESSING AND UNDRESSING EXPERIMENTS.

METABOLISM EXPERIMENT No. 158.

Subject, H. G., February 24, 1905. Age, 22 years 5 months; height, 160 cm.; weight without clothing, 49.2 kilos.

The subject (a student) entered the chamber at about 8 a. m., after a breakfast consisting of prepared cereal, 1 glass of milk, 1 tablespoonful of sugar, and a cup of coffee. He was weighed at 8^h 02^m a. m. and the experiment began at 9^h 15^m a. m. At 9^h 18^m a. m., and again at 11^h 08^m a. m., he went to the food aperture. The rest period, during which there was some writing,[1] continued until 12^h 15^m p. m.

[1] The first three hours of this experiment and the following 21 experiments comprised a part of a study of the influence of mental work on metabolism. The subjects were all students and this was their first experiment. Benedict and Carpenter, U. S. Dept. of Agr., Office Exp. Stas. Bul. 208, 1909.

A special experimental period to study the metabolism during the process of dressing and undressing began at $12^h 15^m$ p. m. and continued 1 hour. At the beginning of this period the subject rose, opened the food aperture to obtain the clinical thermometer, and then sat down. Later he rose again to replace the thermometer and then sat down for a few minutes. He then rose, lowered the end shields from around the heat absorbers,[1] lifted the chair in which he had been sitting to its swinging supports, sat down in it, and was weighed. He next removed the chair and at $12^h 28^m$ p. m. began to undress. The subject then suspended the chair again and sat in it without clothing while being weighed. The length of time from the moment the subject removed the last piece of clothing until he began to dress again was $2^m 10^s$. After he was weighed he took down the chair, dressed, and then went to the food aperture and opened it. He next raised the portion of the shields which he had lowered and sat down in the chair and remained quiet until the end of the period.

The pulse-rates as taken by the subject for the 3 hours of the rest experiment and the 1 hour of the undressing experiment were as follows: $8^h 07^m$ a. m., 71; $8^h 40^m$ a. m., 72; $9^h 15^m$ a. m., 69; $9^h 45^m$ a. m., 66; $10^h 15^m$ a. m., 73; $10^h 45^m$ a. m., 71; $11^h 15^m$ a. m., 62; $11^h 50^m$ a. m., 69; $12^h 40^m$ p. m., 75. The sublingual body-temperatures were at $9^h 15^m$ a. m., 98.1° F.; $12^h 15^m$ p. m., 98.2° F.; $1^h 15^m$ p. m., 98.1° F. The results of the metabolism as obtained for the 3 hours of rest and 1 hour of activity are given in table 44. In this and all the subsequent experiments of this type, it was practicable to subdivide the 3-hour rest experiment into two periods of equal length.

METABOLISM EXPERIMENT No. 159.

Subject, H. L. W., February 24, 1905. Age, 26 years 11 months; height, 164 cm.; weight without clothing, 51.6 kilos.

The subject entered the chamber at about 1 p. m., after a dinner consisting of roast beef, potato with gravy, a dish of peas, 1 biscuit, bread pudding, and a glass of milk. He was weighed at $1^h 20^m$ p. m. and the first period began at $2^h 22^m$ p. m. At $2^h 25^m$ p. m. he went to the food aperture. Most of the time until $5^h 22^m$ p. m. he was writing. The undressing period began at $5^h 22^m$ p. m. and continued to $6^h 22^m$ p. m. The subject during this latter period followed the same routine as during the corresponding period in the preceding experiment (experiment No. 158), resting at the beginning of the period, procuring the thermometer and replacing it in the food aperture and then lowering the shields and suspending the chair. He was then weighed and afterwards took down the chair, undressed, suspended the chair, and was weighed again. He then dressed, went to the food aperture, raised the shields, and at $5^h 54^m$ p. m., sat down and remained quiet until the end of the period. The length of time that the subject was entirely undressed was $3^m 50^s$.

[1] For a description of this apparatus see Carnegie Institution of Washington Publication No. 42, p. 125.

The pulse-rate as recorded by the subject during the 3 hours of the rest experiment was as follows: $2^h\,05^m$ p. m., 86; $2^h\,30^m$ p. m., 80; 3 p. m., 80; $3^h\,35^m$ p. m., 74; 4 p. m., 68; $4^h\,35^m$ p. m., 69; $5^h\,05^m$ p. m., 69. The sublingual body-temperatures taken at the beginning and end of the 3-hour experiment and the subsequent 1-hour period were as follows: $2^h\,22^m$ p. m., 99.0° F.; $5^h\,22^m$ p. m., 98.3° F.; $6^h\,22^m$ p. m., 98.8° F. The results of the metabolism as obtained for the 3 hours of rest and the 1 hour of activity are given in table 44.

METABOLISM EXPERIMENT No. 160.

Subject, F. E. R., February 25, 1905. Age, 20 years 5 months; height, 168 cm.; weight without clothing, 52.9 kilos.

The subject entered the calorimeter chamber at about 8 a. m., after a breakfast of oatmeal with milk and sugar, coffee with cream and sugar, and water, and was weighed at $8^h\,02^m$ a. m. The experiment began at 9 a. m., and during the greater part of the 3 hours following the subject was occupied in writing. At $9^h\,06^m$ a. m. he went to the food aperture. The undressing period was from 12 noon to 1 p. m. During this period the subject's activity was practically the same as that of the subjects of the two previous experiments. The length of time he was without clothing was 3 minutes.

The pulse-rate as taken by the subject was as follows: $8^h\,12^m$ a. m., 99; $9^h\,20^m$ a. m., 94; $9^h\,39^m$ a. m., 97; $10^h\,02^m$ a. m., 86; $10^h\,35^m$ a. m., 82; 11 a. m., 88; $11^h\,23^m$ a. m., 88; $12^h\,03^m$ p. m., 90; $12^h\,33^m$ p. m., 108; 1 p. m., 94. The sublingual body-temperatures were as follows: 9 a. m., 99.3° F.; 12 noon, 99.2° F.; 1 p. m., 99.5° F. The results of the metabolism for both the rest period and the undressing period are given in table 44.

METABOLISM EXPERIMENT No. 161.

Subject, F. N. C., February 25, 1905. Age, 19 years 1 month; height, 168 cm.; weight without clothing, 57.4 kilos.

The subject entered the respiration chamber after a dinner consisting of corn beef, potato, corn fritters, and a piece of jelly cake. He was weighed at $1^h\,20^m$ p. m. and the experiment began at 2 p. m. The first 3 hours of the experiment was spent for the most part in writing—plain copying. At $2^h\,03^m$ p. m. and at $4^h\,44^m$ p. m. the subject went to the food aperture. The undressing period was from 5 p. m. to 6 p. m., and the subject followed the same routine of activity during this time as was followed by the preceding subjects in this series.

The pulse-rate for the 3 hours of the rest experiment as recorded at intervals by the subject was as follows: $2^h\,03^m$ p. m., 72; $2^h\,30^m$ p. m., 72; 3 p. m., 64; $3^h\,30^m$ p. m., 70; $4^h\,15^m$ p. m., 70; $4^h\,30^m$ p. m., 62; $4^h\,55^m$ p. m., 64. The sublingual body-temperature for the beginning and end of the 3-hour and 1-hour periods was as follows: 2 p. m., 97.8° F.; 5 p. m., 97.5° F.; 6 p. m., 97.9° F. The results of the metabolism are given in table 44.

METABOLISM EXPERIMENT No. 162.

Subject, H. C. A., February 27, 1905. Age, 21 years 4 months; height, 172 cm.; weight without clothing, 59.0 kilos.

The subject (a student) ate breakfast consisting of coffee with milk and sugar, one-half glass of milk, 3 or 4 crackers, and half a dozen graham biscuits with butter before entering the chamber. He was weighed at $8^h\,10^m$ a. m. and the experiment began at $8^h\,52^m$ a. m. The rest period continued until $11^h\,52^m$ a. m., the subject occupying most of the time in copying from a report and a magazine. At $8^h\,56^m$ a. m. he went to the food aperture, and at $10^h\,32^m$ a. m. and at $10^h\,46^m$ a. m. he rose and changed the position of his chair. The undressing period was from $11^h\,52^m$ a. m. to $12^h\,52^m$ p. m., and he went through the usual routine for this period. The subject was undressed $5^m\,54^s$, a somewhat longer period then with most of the other men.

The pulse-rate as recorded by the subject for the whole experiment was as follows: 9 a. m., 69; $9^h\,51^m$ a. m., 58; $10^h\,28^m$ a. m., 54; $10^h\,58^m$ a. m., 54; $11^h\,36^m$ a. m., 48. The sublingual body-temperature was as follows: $8^h\,52^m$ a. m., 97.8° F.; $11^h\,52^m$ a. m., 97.3° F.; $12^h\,52^m$ p. m., 97.6° F. The results of the metabolism are given in table 44.

METABOLISM EXPERIMENT No. 163.

Subject, N. M. P., February 27, 1905. Age, 21 years 2 months; height, 179 cm.; weight without clothing, 69.8 kilos.

The subject entered the respiration chamber about 1 p. m. and soon afterward had a lunch consisting of 4 chicken sandwiches, 2 cups of cocoa, and 1 orange. The rest period began at 2 p. m. and lasted until 5 p. m., during which time he copied material from a magazine and a report. At $2^h\,01^m$ p. m. he went to the food aperture. During the undressing period from 5 p. m. to 6 p. m., he went through the same routine as did the subjects in similar experiments. He was undressed $2^m\,8^s$.

The subject took his own pulse-rate, which was as follows: $1^h\,58^m$ p. m., 73; $2^h\,35^m$ p. m., 73; $3^h\,15^m$ p. m., 64; $3^h\,58^m$ p. m., 62; $4^h\,57^m$ p. m., 59; $5^h\,55^m$ p. m., 56. The sublingual body-temperature was as follows: 2 p. m., 98.7° F.; 5 p. m., 98.4° F.; 6 p. m., 98.4° F. The results of the metabolism during the rest period and the undressing period are given in table 44.

METABOLISM EXPERIMENT No. 164.

Subject, J. A. R., February 28, 1905. Age, 23 years 7 months; height, 180 cm.; weight without clothing, 59.0 kilos.

Before entering the chamber the subject had a breakfast consisting of 2.5 tablespoonfuls of prepared cereal with milk and sugar and a small slice of graham bread. He was weighed at $8^h\,05^m$ a. m. and the rest period began at $9^h\,15^m$ a. m. and lasted until $12^h\,15^m$ p. m. At $9^h\,22^m$ a. m. he went to the food aperture. During the greater part of this time he was occupied in writing,

doing plain copying. The undressing period was from $12^h 15^m$ p. m. to $1^h 15^m$ p. m., and the subject followed the usual routine for the undressing period. He was without clothing $2^m 36^s$.

The pulse-rate as taken by the subject was as follows: $8^h 25^m$ a. m., 86; $10^h 35^m$ a. m., 77; $10^h 37^m$ a. m., 75; $10^h 41^m$ a. m., 82; 12 noon, 65; $12^h 02^m$ p. m., 68; $12^h 14^m$ p. m., 70. The sublingual body-temperature as taken in this experiment was as follows: $9^h 15^m$ a. m., 98.4° F.; $12^h 15^m$ p. m., 97.8° F.; $1^h 15^m$ p. m., 97.9° F. The results of the metabolism are recorded in table 44.

METABOLISM EXPERIMENT No. 165.

Subject, H. D. A., February 28, 1905. Age, 21 years 6 months; height, 161 cm.; weight without clothing, 67.2 kilos.

The subject entered the chamber at 1 o'clock, after a dinner consisting of meat pie, potato, stewed tomatoes, and an orange. He was weighed at $1^h 24^m$ p. m. and the rest period began at $2^h 03^m$ p. m., and continued until $5^h 03^m$ p. m. During the first 2 hours the subject was writing. At $2^h 06^m$ p. m. he went to the food aperture. The undressing period was from $5^h 03^m$ p. m. to $6^h 03^m$ p. m. The routine followed was the same as in the preceding experiments; the subject was undressed $6^m 46^s$.

The pulse-rate was recorded by the subject as usual and was as follows: 2 p. m., 82; $2^h 30^m$ p. m., 73; 3 p. m., 71; $3^h 32^m$ p. m., 69; 4 p. m., 65; $4^h 30^m$ p. m., 67; $4^h 58^m$ p. m., 66; $5^h 28^m$ p. m., 63; 6 p. m., 67. The sublingual body-temperature was as follows: $2^h 03^m$ p. m., 98.5° F.; $5^h 03^m$ p. m., 98.0° F.; $6^h 03^m$ p. m., 98.1° F. The results of the metabolism for the experiment are recorded in table 44.

METABOLISM EXPERIMENT No. 166.

Subject, H. L. K., March 1, 1905. Age, 23 years 4 months; height, 166 cm.; weight without clothing, 57.1 kilos.

The subject, who was also used in experiment No. 130, entered the respiration chamber after a breakfast consisting of 1 banana, 4 tablespoonfuls of prepared cereal, 15 teaspoonfuls of light cream, a cup of coffee with 10 teaspoonfuls of heavy cream, and 2 teaspoonfuls of sugar, 1 egg, 1 biscuit, and 1 doughnut. He was weighed at 8 a. m. and the rest period began at $8^h 54^m$ a. m., and continued until $11^h 54^m$ a. m. A part of this time he was occupied in copying from reports and a magazine. At $8^h 58^m$ a. m. he went to the food aperture. The undressing period was from $11^h 54^m$ a. m. to $12^h 54^m$ p. m., and during this time he went through the usual routine of opening the food aperture twice, lowering the shields, hanging the chair, being weighed, and then taking down the chair, undressing, hanging the chair again, being weighed, and then dressing, opening the food aperture, and raising the shields. The subject was undressed $2^m 9^s$.

The pulse-rate as taken by the subject during the 3 hours of the rest period was as follows: $8^h 15^m$ a. m., 95; $8^h 28^m$ a. m., 90; $8^h 35^m$ a. m., 93; $8^h 45^m$ a. m., 98; $8^h 57^m$ a. m., 91; $9^h 20^m$ a. m., 83; $9^h 35^m$ a. m., 84; $9^h 50^m$ a. m., 71; $10^h 15^m$ a. m., 72; $10^h 45^m$ a. m., 75; $11^h 15^m$ a. m., 70; $11^h 45^m$ a. m., 76. The sublingual body-temperature during the whole experiment was as follows: $8^h 54^m$ a. m., 98.1° F.; $11^h 54^m$ a. m., 98.5° F.; $12^h 54^m$ p. m., 98.8° F. The results of the metabolism are recorded in table 44.

METABOLISM EXPERIMENT No. 167.

Subject, A. M., March 1, 1905. Age, 21 years 7 months; height, 175 cm.; weight without clothing, 66.6 kilos.

The subject entered the respiration chamber after a dinner consisting of 1 plate of soup, baked beans, fried potatoes, 4 pieces of toast, a glass of milk, a cup of tea and an apple. He was weighed at $1^h 14^m$ p. m.; the rest period began at $1^h 48^m$ p. m., and continued until $4^h 48^m$ p. m. During this period the subject was occupied with copying. At $1^h 53^m$ p. m. he went to the food aperture. The undressing period was from $4^h 48^m$ p. m. to $5^h 48^m$ p. m., and during this time the subject went through the regular routine that had been prescribed for the other experiments. He was undressed $4^m 34^s$.

The pulse-rate as taken by the subject was as follows: 2 p. m., 81; $2^h 45^m$ p. m., 76; $3^h 30^m$ p. m., 73; $4^h 15^m$ p. m., 70. The sublingual body-temperatures were as follows: $1^h 48^m$ p. m., 98.8° F.; $4^h 48^m$ p. m., 98.3° F.; $5^h 48^m$ p. m., 98.7° F. The results of the metabolism are recorded in table 44.

METABOLISM EXPERIMENT No. 168.

Subject, D. R. F., March 2, 1905. Age, 23 years; height, 173 cm.; weight without clothing, 62.6 kilos.

Before entering the respiration chamber at 8 a. m., the subject ate breakfast consisting of oatmeal and milk, soda crackers, a biscuit, and an apple. He was weighed at $8^h 14^m$ a. m. and the rest period began at $8^h 46^m$ a. m. and continued until $11^h 46^m$ a. m. At $8^h 50^m$ a. m. he went to the food aperture. The remainder of this period was spent in the usual copying. The undressing period was from $11^h 46^m$ a. m. to $12^h 46^m$ p. m. The subject went through the usual routine during this period, and at $12^h 06^m$ p. m., after being weighed undressed, he passed 199 grams of urine. The subject was without clothing $2^m 5^s$.

The pulse-rate as taken by the subject was as follows: $8^h 24^m$ a. m., 83; 9 a. m., 87; $9^h 45^m$ a. m., 80; $10^h 15^m$ a. m., 72; 11 a. m., 70; $11^h 30^m$ a. m., 68 The sublingual body-temperature was at $8^h 46^m$ a. m., 98.0° F.; $11^h 46^m$ a. m., 97.7° F.; $12^h 46^m$ p. m., 98.0° F. The results of the metabolism are recorded in table 44.

METABOLISM EXPERIMENT No. 169.

Subject, J. N. T., March 2, 1905. Age, 21 years 10 months; height, 173 cm.; weight without clothing, 63.5 kilos.

The subject entered the calorimeter at about 1 p. m., after eating a dinner consisting of 1 pork chop, 2 boiled potatoes, a dish of onions, 2 pieces of bread, and 1 piece of prune pie. He was weighed at $1^h 07^m$ p. m. and the rest period began at $2^h 16^m$ p. m. and continued until $5^h 16^m$ p. m. At $2^h 18^m$ p. m. he went to the food aperture. During most of this period he was occupied in writing. The undressing period was from $5^h 16^m$ p. m. to $6^h 16^m$ p. m. The subject was undressed $3^m 15^s$.

The pulse-rate as taken by the subject was as follows: $1^h 45^m$ p. m., 78; $2^h 30^m$ p. m., 93; $3^h 30^m$ p. m., 73; $4^h 30^m$ p. m., 63; 5 p. m., 61. The sublingual body-temperature was as follows: $2^h 16^m$ p. m., 98.7° F.; $5^h 16^m$ p. m., 97.7° F.; $6^h 16^m$ p. m., 98.2° F. The results of the metabolism for the experiment are given in table 44.

METABOLISM EXPERIMENT No. 170.

Subject, C. A. R., March 18, 1905. Age, 18 years 11 months; height, 174 cm.; weight without clothing, 59.7 kilos.

The subject entered the respiration chamber at about 8 a. m. Previous to this he had eaten breakfast consisting of 2 dishes of oatmeal, fried potatoes, and a glass of milk. He was weighed at $8^h 16^m$ a. m.; the rest period began at $8^h 57^m$ a. m. and continued until $11^h 57^m$ a. m. During this time he was copying from reports and from a magazine. At $9^h 01^m$ a. m. he went to the food aperture. The undressing period was from $11^h 57^m$ a. m. to $12^h 58^m$ p. m., and the subject followed the usual routine for the period. He was undressed $2^m 21^s$. He was somewhat drowsy for a few minutes at the end of the period. He stood up and sat down at $12^h 40^m$ p. m.

The pulse-rate as recorded by the subject during the experiment was as follows: 9 a. m., 108; $9^h 30^m$ a. m., 100; 10 a. m., 95; $10^h 30^m$ a. m., 87; 11 a. m., 89; $11^h 30^m$ a. m., 77; 12 noon, 78; $12^h 30^m$ p. m., 85. The sublingual body-temperature was at $8^h 57^m$ a. m., 98.3° F.; $11^h 57^m$ a. m., 98° F.; $12^h 58^m$ p. m., 98.4° F. The results of the metabolism for the experiment are recorded in table 44.

METABOLISM EXPERIMENT No. 171.

Subject, A. G., March 18, 1905. Age, 24 years 1 month; height, 170 cm.; weight without clothing, 63.3 kilos.

The subject entered the chamber at 1 p. m., after a dinner consisting of roast pork, potatoes, 3 slices of bread with butter, lemon pie, and prunes. He was weighed at $1^h 12^m$ p. m. and the rest period began at 2 p. m. and continued until 5 p. m. Part of the time he wrote, copying from a magazine and a report. At $2^h 01^m$ p. m. he went to the food aperture. At 3 p. m. it was

noticed that he was asleep and he was waked up by telephone. The undressing period was from 5 p. m. to 6 p. m. and the usual routine was followed. The subject was without clothing for $2^m 51^s$.

The pulse-rate during the first 3 hours as taken by the subject was as follows: $2^h 04^m$ p. m., 92; $2^h 30^m$ p. m., 84; $3^h 07^m$ p. m., 84; $3^h 20^m$ p. m., 72; $3^h 50^m$ p. m., 72; $4^h 30^m$ p. m., 66; $4^h 55^m$ p. m., 70. The sublingual body-temperature was as follows: 2 p. m., 97.9° F.; 5 p. m., 97.7° F.; 6 p. m., 98° F. The results of the metabolism are given in table 44.

METABOLISM EXPERIMENT No. 172.

Subject, G. G. R., March 20, 1905. Age, 19 years 11 months; height, 178 cm.; weight without clothing, 77.2 kilos.

The subject entered the respiration chamber after a breakfast consisting of 2 dishes of cooked cereal and milk, milk toast, and coffee. He was weighed at $8^h 01^m$ a. m.; the rest period began at $8^h 53^m$ a. m. and continued until $12^h 53^m$ p. m. Most of the time the subject was copying from a report and from a magazine. At $8^h 55^m$ a. m. he went to the food aperture. The undressing period was from $1^h 53^m$ a. m. to $12^h 53^m$ p. m., the subject following the regular routine for these experiments. From $12^h 24^m$ p. m. until the end of the experiment he sat quietly reading. The subject was undressed $2^m 28^s$.

The pulse-rate as taken by the subject during the first 3 hours was as follows: 9 a. m., 76; $9^h 45^m$ a. m., 70; $10^h 30^m$ a. m., 70; $11^h 15^m$ a. m., 68; 12 noon, 69. The sublingual body-temperature was at $8^h 53^m$ a. m., 98.6° F.; $11^h 53^m$ a. m., 98.5° F.; $12^h 53^m$ p. m., 98.6° F. The results of the metabolism are given in table 44.

METABOLISM EXPERIMENT No. 173.

Subject, J. V. C., March 21, 1905. Age, 22 years 1 month; height, 173 cm.; weight without clothing, 63.1 kilos.

The subject entered the chamber at about 8 a. m. and was weighed at $8^h 01^m$ a. m. Previous to entering he had eaten a breakfast consisting of 3 pancakes with butter and sirup and 1 cup of coffee with sugar and milk. The rest period began at $8^h 48^m$ a. m. and continued until $11^h 48^m$ a. m. During most of the time the subject was occupied in copying from a report and from a magazine. At $8^h 51^m$ a. m. he went to the food aperture. He drank 106 c. c. of water at $9^h 08^m$ a. m., and at $10^h 22^m$ a. m. he passed 380 grams of urine. He finished copying at $11^h 40^m$ a. m. and then remained quietly in the chair until $11^h 48^m$ a. m., at which time the undressing period began. The subject followed the usual routine connected with the undressing and on completing this at $12^h 12^m$ p. m. he sat down and read until the end of the experiment at $12^h 48^m$ p. m. The subject was undressed $2^m 3^s$.

The pulse-rate for the experiment as taken by the subject was as follows: $8^h 33^m$ a. m., 74; $8^h 55^m$ a. m., 74; $9^h 25^m$ a. m., 75; $9^h 55^m$ a. m., 67; $10^h 25^m$

a. m., 66; $10^h\ 55^m$ a. m., 60; $11^h\ 25^m$ a. m., 65; $11^h\ 40^m$ a. m., 65. The sublingual body-temperature was at $8^h\ 48^m$ a. m., 98° F.; $11^h\ 48^m$ a. m., 97.9° F.; $12^h\ 48^m$ p. m., 97.9° F. The results of the metabolism for the experiment are given in table 44.

METABOLISM EXPERIMENT No. 174.

Subject, E. M. S., March 21, 1905. Age, 27 years 1 month; height, 175 cm.; weight without clothing, 64.6 kilos.

The subject entered the respiration chamber at 1 p. m. and was weighed at $1^h\ 33^m$ p. m. The last meal taken previous to entering the chamber was at $9^h\ 15^m$ a. m., at which time the subject ate 1 banana, a portion of prepared cereal with 3 teaspoonfuls of sugar, and about one-fourth pint of cream, a few raisins, 1 fig, one-half pint of milk, a slice of whole-wheat bread, and a small amount of peanut butter. The rest period, during which the subject copied most of the time, began at $2^h\ 16^m$ p. m. and continued until $5^h\ 16^m$ p. m. At $2^h\ 19^m$ p. m. he went to the food aperture. The undressing period continued from $5^h\ 16^m$ p. m. to $6^h\ 16^m$ p. m. The subject finished the routine of weighing and undressing at $5^h\ 40^m$ p. m. and the rest of the time remained quiet with the exception of a little reading. He was undressed $2^m\ 27^s$.

The pulse-rate as taken by the subject was as follows: $2^h\ 30^m$ p. m., 80; $2^h\ 50^m$ p. m., 78; $3^h\ 20^m$ p. m., 74; $3^h\ 43^m$ p. m., 72; $4^h\ 14^m$ p. m., 76; $4^h\ 50^m$ p. m., 75; $5^h\ 12^m$ p. m., 74. The sublingual body-temperature was at $2^h\ 16^m$ p. m., 98.4° F.; $5^h\ 16^m$ p. m., 98.2° F.; $6^h\ 16^m$ p. m., 98.4° F. The results of the metabolism for the experiment are given in table 44.

METABOLISM EXPERIMENT No. 175.

Subject, G. E. H., March 22, 1905. Age, 27 years 1 month; height, 179 cm.; weight without clothing, 63.1 kilos.

The subject entered the respiration chamber at 8 o'clock after a breakfast consisting of rolled oats and milk and a muffin, and was weighed at $8^h\ 03^m$ a. m. The rest period began at $9^h\ 07^m$ a. m. and ended at $12^h\ 07^m$ p. m., the subject being occupied with copying most of the time. At $9^h\ 09^m$ a. m. he went to the food aperture. He was asleep for a moment at $9^h\ 36^m$ a. m. The undressing period was from $12^h\ 07^m$ p. m. until $1^h\ 07^m$ p. m. The subject went through the routine for this period as usual, except that the weight with clothing was taken twice. He finished at $12^h\ 38^m$ p. m. and sat reading until $1^h\ 07^m$ p. m. He was undressed 6^m.

The pulse-rate as taken by the subject was as follows: $9^h\ 10^m$ a. m., 61; 10 a. m., 58; $10^h\ 30^m$ a. m., 60; $11^h\ 30^m$ a. m., 56; $11^h\ 56^m$ a. m., 60. The sublingual body-temperature was taken only at the beginning and end of the rest period, and was at $9^h\ 07^m$ a. m., 97.5° F., and at $12^h\ 07^m$ p. m., 97.4° F. The results of the metabolism for the experiment are given in table 44.

METABOLISM EXPERIMENT No. 176.

Subject, G. H. H., March 23, 1905. Age, 21 years 4 months; height, 163 cm.; weight without clothing, 51.7 kilos.

The subject entered the respiration chamber after a breakfast consisting of prepared cereal with sugar and milk, 2 biscuits and a glass of milk, and was weighed at $7^h 55^m$ a.m. The experiment began at $8^h 47^m$ a.m., and the first rest period ended at $9^h 56^m$ a.m. The second rest period was from $9^h 56^m$ a.m. to $11^h 56^m$ a.m. The subject did the usual copying during this period. At $8^h 49^m$ a.m. he went to the food aperture. The undressing period was from $11^h 56^m$ a.m. to $12^h 56^m$ p.m. The subject followed the usual routine for this period, but there was more muscular activity than with some of the other subjects. He finished the routine at $12^h 24^m$ p.m. and remained quiet until the end of the experiment at $12^h 56^m$ p.m. The subject was undressed $2^m 24^s$.

The pulse-rate as taken by the subject was as follows: $9^h 05^m$ a.m., 97; $9^h 34^m$ a.m., 90; $10^h 09^m$ a.m., 88; $10^h 45^m$ a.m., 85; $11^h 15^m$ a.m., 91; $11^h 45^m$ a.m., 85. The sublingual body-temperature was taken as usual, and was as follows: 8 47^m a.m., 98.5° F.; $11^h 56^m$ a.m., 98.6° F.; $12^h 56^m$ p.m., 99° F. The results of the metabolism for the experiment are recorded in table 44.

METABOLISM EXPERIMENT No. 177.

Subject, J. W. H., March 23, 1905. Age, 29 years 1 month; height, 175 cm.; weight without clothing, 61.2 kilos.

The subject entered the respiration chamber after a lunch consisting of 2 glasses of milk, 2 slices of bread and butter, 4 slices of corned beef with horseradish, and 2 pieces of cake, and was weighed at $1^h 05^m$ p.m. The rest period began at $1^h 40^m$ p.m. and continued until $4^h 40^m$ p.m., during which time the subject was engaged in copying, although not all of the time was thus occupied. At $1^h 44^m$ p.m. he went to the food aperture, and again at $3^h 19^m$ p.m. The undressing period was from $4^h 40^m$ p.m. to $5^h 40^m$ p.m., and the regular routine was finished at $5^h 07^m$ p.m. The subject was undressed $3^m 32^s$.

The pulse-rate as taken by the subject was as follows: $1^h 50^m$ p.m., 71; $2^h 35^m$ p.m., 69; $3^h 30^m$ p.m., 70; $4^h 30^m$ p.m., 69. The sublingual body-temperature, taken as usual, was as follows: $1^h 40^m$ p.m., 98.5° F.; $4^h 40^m$ p.m., 98.3° F.; $5^h 40^m$ p.m., 98.6° F. The results of the metabolism for the experiment are recorded in table 44.

METABOLISM EXPERIMENT No. 178.

Subject, G. W. S., March 25, 1905. Age, 20 years 1 month; height, 173 cm.; weight without clothing, 50.7 kilos.

The subject entered the respiration chamber after a breakfast consisting of 2 dishes of oatmeal and 3 muffins and was weighed at $8^h 09^m$ a.m. The

rest period began at $9^h 10^m$ a.m. and continued until $12^h 10^m$ p.m., the subject being busy most of the time with the usual copying. At $9^h 14^m$ a.m. he went to the food aperture. During the period from $12^h 10^m$ p.m. to $1^h 10^m$ p.m., a part of the time was occupied in the undressing and weighing processes, which were finished at $12^h 35^m$ p.m. From $12^h 35^m$ p.m. until $1^h 10^m$ p.m. the subject remained quiet. He was undressed $5^m 19^s$.

The pulse-rate as obtained by the subject was as follows: $8^h 50^m$ a.m., 93; $9^h 15^m$ a.m., 88; $9^h 45^m$ a.m., 93; $10^h 15^m$ a.m., 81; $10^h 45^m$ a.m., 79; $11^h 15^m$ a.m., 79; $11^h 45^m$ a.m., 80; 12 noon, 79; $12^h 30^m$ p.m., 71. The sublingual body-temperature was as follows: $9^h 10^m$ a.m., 97.4° F.; $12^h 10^m$ p.m., 97.6° F.; $1^h 10^m$ p.m., 97.8° F. The results of the metabolism as obtained in these periods are given in table 44.

EXPERIMENTS WITH WOMEN.

Five experiments were made with two young women who were students in Wesleyan University, and had volunteered to act as subjects. These experiments were conducted on the same plan as that used in the other normal experiments with students and assistants in the laboratory.

METABOLISM EXPERIMENT No. 179.

Subject, C. F. S., June 16, 1905. Age, 21 years 7 months; height, 161 cm.; weight without clothing, 62.2 kilos.

The subject entered the respiration chamber at the usual time for these experiments, that is, about 8 a.m. She had eaten previously a breakfast consisting of bananas, half slice of toast, 3 radishes, and half cup of milk. The experiment began at $9^h 32^m$ a.m. and the subject immediately went to the food aperture and placed the clinical thermometer in it. As she was not familiar with the operation of opening the food aperture, there was considerable muscular effort in doing this, and she was at the food aperture several minutes before finally opening it. She went to the food aperture again at $9^h 46^m$ a.m., opened it, and immediately after sat down. During the first half hour she ate 85 grams of bananas. This experiment consisted of only one $2^h 30^m$ period, ending at $12^h 02^m$ p.m. Most of this time the subject was sitting in the chair reading.

This was the first experience of this subject in the respiration chamber and she was entirely unfamiliar with the apparatus or with any of the operations connected with it, so that there was considerable novelty for her in the experience. However, she made no comments regarding her stay, except to say that the temperature seemed high at first and that it gradually lowered during the experiment.

The pulse-rate per minute as taken by the subject was: $9^h 45^m$ a. m., 84; $10^h 30^m$ a. m., 74; $11^h 20^m$ a. m., 70; 12 noon, 66. The sublingual body-temperature at the beginning of the period was 97.7° F.; and at the end, 97.7° F. The results of the metabolism during the experiment are given in table 44.

METABOLISM EXPERIMENT No. 180.

Subject, C. F. S., June 21, 1905. (Same subject as in experiment No. 179.)

The subject entered the chamber at about 6 p. m., after a supper consisting of 2 slices of bread, 1 saucer of strawberries, and 2½ glasses of milk. The experiment began at $7^h 10^m$ p. m., and there was one period, ending at $9^h 40^m$ p. m. The subject remained quiet in the chair during the whole of the experiment, except that she opened the food aperture once at $8^h 26^m$ p. m. to get a bottle of water, from which she then drank 48 c. c. The only comment made by the subject was that she felt physically tired before entering the calorimeter chamber.

The pulse-rate as recorded by the subject was as follows: $6^h 30^m$ p. m., 89; 7 p. m., 77; $7^h 45^m$ p. m., 85; 8 p. m., 82; $8^h 30^m$ p. m., 72; 9 p. m., 67; $9^h 30^m$ p. m., 67. The sublingual body-temperature at $7^h 10^m$ p. m. was 98.7° F. and at $9^h 48^m$ p. m., 97.2° F. The results of the metabolism during the experiment are given in table 44.

METABOLISM EXPERIMENT No. 181.

Subject, G. E. B., June 22, 1905. Age, 26 years 2 months; height, 157 cm.; weight without clothing, 57.7 kilos.

The subject entered the respiration chamber at 8 a. m., after a breakfast consisting of toast, and ham and eggs. The experiment began at $9^h 18^m$ a. m. and shortly afterwards the subject went to the food aperture and placed the thermometer in it, and sat down. At $10^h 48^m$ a. m., the beginning of the second period, she again took her temperature, opening the food aperture to get the thermometer, sitting down and taking the temperature, then rising and placing the thermometer in the food aperture and sitting down again. The experiment ended at $12^h 18^m$ p. m. The subject read most of the time. This experiment was the first with this subject, and her only comment was that she felt cold during the hour from 9 to 10 a. m.

The pulse-rate as recorded by the subject was as follows: $8^h 20^m$ a. m., 100; $8^h 55^m$ a. m., 84; $9^h 25^m$ a. m., 82; $9^h 55^m$ a. m., 77; $10^h 40^m$ a. m., 74; $11^h 10^m$ a. m., 75; $11^h 55^m$ a. m., 78. The sublingual body-temperatures were as follows: $9^h 18^m$ a. m., 98.7° F.; $10^h 48^m$ a. m., 98.4° F.; $12^h 18^m$ p. m., 98.1° F. The results of the metabolism obtained in the two $1^h 30^m$ periods are given in table 44.

METABOLISM EXPERIMENT No. 182.

Subject, G. E. B., June 23, 1905. (Same subject as in experiment No. 181.)

The breakfast, which consisted of 1 banana, 1 plum, 1 egg, and a roll, was eaten shortly before the subject entered the chamber at 8 a. m. The experiment began at $8^h 54^m$ a. m. At the beginning of the first period, the subject went to the food aperture and placed the thermometer in it, and at the beginning of the second period she went twice to the food aperture, sitting down and taking her temperature between the two operations. The experiment continued until $12^h 54^m$ p. m., and there were two 2-hour periods, during which the subject read most of the time. No comments were made by the subject.

The pulse-rate as recorded by the subject was as follows: $8^h 30^m$ a. m., 91; 9 a. m., 83; $9^h 50^m$ a. m., 76; $10^h 20^m$ a. m., 75; $10^h 55^m$ a. m., 77; $11^h 30^m$ a. m., 75; $12^h 05^m$ p. m., 75; $12^h 45^m$ p. m., 76. The sublingual body-temperatures were as follows: $8^h 54^m$ a. m., 98.9° F.; $10^h 54^m$ a. m., 98.1° F.; $12^h 54^m$ p. m., 98° F. The results of the metabolism during the two 2-hour periods are given in table 44.

METABOLISM EXPERIMENT No. 183.

Subject, G. E. B., June 24, 1905. (Same subject as in experiment No. 181.)

The subject had for breakfast, steak, potato, and biscuit, and entered the respiration chamber shortly after 8 a. m. The experiment began at $9^h 02^m$ a. m. and continued for 4 hours, ending at $1^h 02^m$ p. m. The subject read most of the time during the experiment. She went to the food aperture at the beginning of the first period, placed the thermometer in it, and then sat down again, and at $11^h 06^m$ a. m. she went to the food aperture twice and took her temperature as usual. No comments were made by the subject.

The pulse-rate as recorded by the subject was as follows: $8^h 25^m$ a. m., 87; 9 a. m., 79; $9^h 30^m$ a. m., 75; $10^h 05^m$ a. m., 72; $10^h 40^m$ a. m., 69; $11^h 20^m$ a. m., 69; $11^h 50^m$ a. m., 71; $12^h 25^m$ p. m., 75. The sublingual body-temperature was as follows: $9^h 02^m$ a. m., 98.7° F.; $11^h 02^m$ a. m., 98.2° F.; $1^h 02^m$ p. m., 98.2° F. The results of the metabolism during the experiment are given in table 44.

SUMMARY OF THE RESULTS IN METABOLISM EXPERIMENTS.

The results of the metabolism in the experiments, the statistics of which have been given in the preceding pages, have been summarized in table 44.

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104-183.*

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
104	B. F. D.	Rest, with food.					
	Mar. 3, 1904..	7^{h} 00^{m} a.m. to 10^{h} 00^{m} a.m...	....	125.9	102.7	386.2	....
		10 00 a.m. 1 00 p.m...	....	103.7	63.5	283.7	....
		1 00 p.m. 4 00 p.m...	....	109.5	97.4	341.0	...
		4 00 p.m. 7 00 p.m...	....	124.6	89.0	309.0	....
		Total, 12^{h} 00^{m}...........	....	463.7	352.6	1319.9	....
105	B. F. D.	Rest, without food.					
	May 5-6, 1905.	9^{h} 00^{m} p.m. to 11^{h} 00^{m} p.m...	89.5	65.1	45.9	204.1	....
		11 00 p.m. 1 00 a.m...	92.0	53.1	36.4	158.9	....
	May 6-7, 1905.	1 00 a.m. 3 00 a.m...	89.4	46.5	38.4	134.4	....
		3 00 a.m. 5 00 a.m...	82.9	50.1	39.9	146.2	....
		5 00 a.m. 7 00 a.m...	82.7	50.5	46.2	137.2	....
		7 00 a.m. 9 00 a.m...	87.8	71.4	66.3	199.8	197.2
		9 00 a.m. 11 00 a.m...	77.0	64.2	50.9	196.3	198.6
		11 00 a.m. 1 00 p.m...	71.4	58.2	51.8	177.9	171.2
		1 00 p.m. 3 00 p.m...	71.7	54.7	44.8	[1] 159.4	[1] 159.0
		3 00 p.m. 5 00 p.m...	77.8	62.0	69.0	[2] 185.5	[2] 193.2
		5 00 p.m. 7 00 p.m...	73.5	60.3	59.2	185.0	194.9
		7 00 p.m. 9 00 p.m...	74.0	63.7	49.2	155.1	160.4
		9 00 p.m. 11 00 p.m...	96.2	64.1	66.8	165.8	....
		11 00 p.m. 1 00 a.m...	98.8	65.8	62.8	194.5	....
106	B. F. D.	Rest, with food.					
	May 31, 1905..	2^{h} 28^{m} p.m. to 4^{h} 58^{m} p.m...	117.5	84.1	65.3	262.5	....
107	B. F. D.	Rest, with food.					
	June 2, 1905..	2^{h} 44^{m} p.m. to 4^{h} 45^{m} p.m...	109.3	66.8	52.5	200.2	202.0
		4 45 p.m. 6 45 p.m...	92.3	66.7	55.3	194.6	208.5
		6 45 p.m. 8 45 p.m...	98.9	74.9	65.5	201.1	199.6
		Total, 6^{h} 1^{m}............	300.5	208.4	173.3	595.9	610.1
108	B. F. D.	Rest, with food.					
	June 3, 1905..	12^{h} 45^{m} p.m. to 2^{h} 45^{m} p.m...	104.3	65.5	53.2	189.8	199.6
		2 45 p.m. 4 45 p.m...	111.5	68.8	58.3	145.6	140.4
		4 45 p.m. 6 45 p.m...	101.2	73.0	60.0	229.7	228.4
		6 45 p.m. 8 45 p.m...	97.0	75.2	60.8	221.4	226.5
		8 45 p.m. 10 45 p.m...	86.2	67.0	49.5	199.4	....
		10 45 p.m. 12 45 a.m...	94.2	61.8	51.1	[3] 151.2	....
		12 45 a.m. 1 42 a.m...	62.1	39.6	32.3	[4] 103.1	....
109	J. C. W.	Sleep.					
	Mar. 29, 1904..	1^{h} 00^{m} a.m. to 4^{h} 00^{m} a.m...	122.1	95.5	71.5	227.2	....
		4 00 a.m. 7 00 a.m...	140.7	104.8	78.2	277.5	....
		Total, 6^{h} 00^{m}...........	262.8	200.3	149.7	504.7	....
110	J. T. H.	Mental work, with food.					
	Feb. 20, 1905..	2^{h} 07^{m} p.m. to 3^{h} 37^{m} p.m...	57.9	45.4	40.1	149.6	....
		3 37 p.m. 5^{h} 09^{m} 23^{s} p.m.	58.8	44.6	37.6	146.3	....
		Total, 3^{h} 02^{m} 23^{s}	116.7	90.0	77.7	295.9	285.5
111	C. F. B.	Rest.					
	Jan. 18, 1905..	1^{h} 40^{m} p.m. to 5^{h} 40^{m} p.m...	157.3	143.4	122.7	440.1	....
112	T. M. C.	Rest, with food.					
	Feb. 13, 1905..	2^{h} 06^{m} p.m. to 4^{h} 06^{m} p.m...	66.6	60.9	49.8	199.9	} 390.5
		4 06 p.m. 6 06 p.m...	65.5	57.7	58.7	192.6	
		Total, 4^{h} 00^{m}............	132.1	118.5	108.5	392.5	390.5
113	T. M. C.	Rest, with food.					
	June 7, 1905..	9^{h} 04^{m} a.m. to 11^{h} 04^{m} a.m...	76.6	50.6	34.5	153.4	152.1
		11 04 a.m. 1 04 p.m...	66.3	47.2	41.3	140.0	131.4
		1 04 p.m. 3 04 p.m...	62.4	54.6	46.6	153.0	166.9
		Total, 6^{h} 00^{m}............	205.3	152.4	122.4	446.4	450.4

[1] Correction has been made for 30 calories stored in bed and bedding.
[2] Correction has been made for 30 calories liberated from bed and bedding.
[3] No correction has been made for heat possibly stored in bed and bedding.
[4] No correction has been made for heat possibly liberated from bed and bedding.

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104–183*—Continued.

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
114	H. C. M. Apr. 27, 1905..	Rest, with food.					
		$9^{h}\,56^{m}$ a.m. to $11^{h}\,56^{m}$ a.m...	99.2	77.5	67.2	238.9	237.4
		11 56 a.m. 1 56 p.m...	94.6	79.9	63.0	233.3	233.7
		1 56 p.m. 3 56 p.m...	91.1	75.0	54.2	211.7	201.2
		Total, $6^{h}\,00^{m}$............	284.9	232.4	184.4	683.9	672.3
115	H. C. M. June 9, 1905..	Rest, with food.					
		$9^{h}\,53^{m}$ a.m. to $11^{h}\,53^{m}$ a.m...	99.9	69.9	56.6	221.2	194.8
		11 53 a.m. 1 53 p.m...	93.6	71.8	59.1	210.8	230.5
		1 53 p.m. 3 53 p.m...	89.9	85.2	68.1	212.7	213.8
		Total, $6^{h}\,00^{m}$............	283.4	226.9	183.8	644.7	639.1
116	S. C. D. Apr. 28, 1905..	Rest, with food.					
		$9^{h}\,16^{m}$ a.m. to $11^{h}\,16^{m}$ a.m...	82.9	63.1	53.8	205.9	185.2
		11 16 a.m. 1 16 p.m...	86.1	71.4	61.7	195.8	225.5
		1 16 p.m. 3 16 p.m...	80.8	70.9	57.7	198.1	175.5
		Total, $6^{h}\,00^{m}$............	249.8	205.4	173.2	599.8	586.2
117	S. C. D. June 21, 1905.	Rest, with food.					
		$9^{h}\,17^{m}$ a.m. to $11^{h}\,17^{m}$ a.m...	103.4	79.4	55.9	203.5	190.7
		11 17 a.m. 1 17 p.m...	90.8	66.8	56.7	192.2	212.4
		1 17 p.m. 3 17 p.m...	85.1	71.4	55.4	195.1	197.0
		Total, $6^{h}\,00^{m}$............	279.3	217.6	168.0	590.8	600.1
118	B. N. Apr. 29, 1905..	Rest, with food.					
		$9^{h}\,44^{m}$ a.m. to $11^{h}\,44^{m}$ a.m...	89.3	54.0	47.1	177.1	170.6
		11 44 a.m. 1 44 p.m...	99.4	68.8	58.2	178.5	198.6
		1 44 p.m. 3 44 p.m...	99.2	66.8	53.3	185.3	179.1
		Total, $6^{h}\,00^{m}$............	287.9	189.6	158.6	540.9	518.3
119	B. N. June 5, 1905..	Rest, with food.					
		$10^{h}\,22^{m}$ a.m. to $12^{h}\,22^{m}$ p.m...	91.9	52.1	38.2	160.6	154.2
		12 22 p.m. 2 22 p.m...	80.7	62.2	53.1	162.4	183.9
		2 22 p.m. 4 22 p.m...	77.2	65.1	46.9	169.3	156.3
		Total, $6^{h}\,00^{m}$............	249.8	179.4	138.2	492.3	[1] 491.4
120	B. N. June 15, 1905.	Rest, with food.					
		$10^{h}\,30^{m}$ a.m. to $12^{h}\,30^{m}$ p.m...	100.5	57.3	44.7	170.1	177.6
		12 30 p.m. 2 30 p.m...	104.5	65.9	52.4	171.3	176.4
		2 30 p.m. 4 30 p.m...	93.1	60.5	49.9	163.3	166.4
		Total, $6^{h}\,00^{m}$............	298.1	183.7	147.0	504.7	[1] 513.0
121	F. L. T. May 1, 1905...	Rest, with food.					
		$9^{h}\,23^{m}$ a.m. to $11^{h}\,23^{m}$ a.m...	82.8	61.0	51.4	210.0	191.9
		11 23 a.m. 1 23 p.m...	83.3	83.6	71.1	214.6	237.8
		1 23 p.m. 3 23 p.m...	85.6	77.5	68.9	216.0	208.5
		Total, $6^{h}\,00^{m}$............	251.7	222.1	191.4	640.6	638.2
122	W. R. L. May 2, 1905...	Rest, with food.					
		$10^{h}\,28^{m}$ a.m. to $12^{h}\,28^{m}$ p.m...	83.9	69.0	47.1	229.1	187.6
		12 28 p.m. 2 28 p.m...	88.8	86.4	71.0	215.6	254.1
		2 28 p.m. 4 28 p.m...	86.4	81.6	62.6	225.1	216.4
		Total, $6^{h}\,00^{m}$............	259.1	237.0	180.7	669.8	658.1
123	W. H. L. May 9, 1905...	Rest, with food.					
		$9^{h}\,43^{m}$ a.m. to $11^{h}\,43^{m}$ a.m...	85.8	65.5	49.9	174.4	160.7
		11 43 a.m. 1 43 p.m...	83.4	74.8	56.3	186.3	195.7
		1 43 p.m. 3 43 p.m...	76.8	68.5	51.7	187.3	186.0
		Total, $6^{h}\,00^{m}$............	246.0	208.8	157.9	548.0	542.4
124	W. H. L. June 6, 1905..	Rest, with food.					
		$9^{h}\,07^{m}$ a.m. to $11^{h}\,07^{m}$ a.m...	92.8	68.4	48.8	192.4	190.8
		11 07 a.m. 1 07 p.m...	87.2	67.5	54.4	178.4	197.4
		1 07 p.m. 3 07 p.m...	77.9	71.4	53.9	180.4	172.6
		Total, $6^{h}\,00^{m}$............	257.9	207.3	157.1	551.2	560.8

[1] Correction has been made here for heat from urine voided during the experiment.

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104–183*—Continued.

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
125	F. W. H. May 10, 1905..	Rest, with food.					
		9h 13m a.m. to 11h 13m a.m...	91.3	57.3	43.9	190.3	185.7
		11 13 a.m. 1 13 p.m...	85.7	67.1	55.5	189.6	193.0
		1 13 p.m. 3 13 p.m...	83.2	62.5	53.3	176.9	164.2
		Total, 6h 00m	260.2	186.9	152.7	556.8	542.9
126	J. R. May 11, 1905..	Rest, with food.					
		9h 00m a.m. to 11h 00m a.m...	81.3	75.2	55.1	213.2	208.2
		11 00 a.m. 1 00 p.m...	76.3	75.6	66.9	202.9	223.6
		1 00 p.m. 3 00 p.m...	79.1	74.8	56.0	198.6	194.2
		Total, 6h 00m	236.7	225.6	178.0	614.7	626.0
127	R. D. M. May 12, 1905..	Rest, with food.					
		8h 48m a.m. to 10h 48m a.m...	85.1	59.1	41.9	189.8	174.2
		10 48 a.m. 12 48 p.m...	83.5	68.8	65.7	185.2	195.3
		12 48 p.m. 2 48 p.m...	75.7	68.4	49.0	180.9	186.5
		Total, 6h 00m	244.3	196.3	156.6	555.9	556.0
128	R. A. M. June 8, 1905..	Rest, with food.					
		9h 24m a.m. to 11h 24m a.m...	95.5	67.4	52.3	203.8	196.0
		11 24 a.m. 1 24 p.m...	93.1	70.6	60.5	201.9	209.5
		1 24 p.m. 3 24 p.m...	87.3	70.9	62.3	200.0	189.6
		Total, 6h 00m	275.9	208.9	175.1	605.7	595.1
129	R. A. M. June 13, 1905.	Rest, with food.					
		9h 42m a.m. to 11h 42m a.m...	100.2	65.5	53.7	198.3	196.8
		11 42 a.m. 1 42 p.m...	101.1	71.0	55.2	195.9	205.9
		1 42 p.m. 3 42 p.m...	94.4	72.0	60.4	193.7	189.3
		Total, 6h 00m	295.7	208.5	169.3	587.9	592.0
130	H. L. K. June 10, 1905.	Rest, with food.					
		8h 39m a.m. to 10h 39m a.m...	90.8	57.6	46.5	181.9	177.5
		10 39 a.m. 12 39 p.m...	83.1	63.0	55.8	176.8	192.2
		12 39 p.m. 2 39 p.m...	79.3	66.1	56.9	178.1	177.8
		Total, 6h 00m	253.2	186.7	159.2	536.8	547.5
131	H. A. P. June 12, 1905.	Rest, with food.					
		9h 44m a.m. to 11h 44m a.m...	93.8	55.7	38.4	181.0	158.6
		11 44 a.m. 1 44 p.m...	87.6	60.5	54.3	178.1	186.1
		1 44 p.m. 3 44 p.m...	77.4	58.7	44.9	173.3	163.1
		Total, 6h 00m	258.8	174.9	137.6	532.4	507.8
132	H. A. P. June 20, 1905.	Rest, with food.					
		9h 10m a.m. to 11h 10m a.m...	105.6	58.8	47.2	182.1	171.1
		11 10 a.m. 1 10 p.m...	103.6	64.3	51.5	183.7	181.7
		1 10 p.m. 3 10 p.m...	89.8	63.6	53.0	181.4	161.0
		Total, 6h 00m	299.0	186.7	151.7	547.2	513.8
133	W. E. D. June 14, 1905.	Rest, with food.					
		9h 22m a.m. to 11h 22m a.m...	106.5	76.0	66.6	215.2	188.2
		11 22 a.m. 1 22 p.m...	100.2	78.3	54.2	209.9	245.8
		1 22 p.m. 3 22 p.m...	109.7	82.9	71.1	212.6	213.7
		Total, 6h 00m	316.4	237.2	191.9	637.7	[1] 644.5
134	C. R. Y. Oct. 4-5, 1905.	Rest, with food.					
		1h 00m p.m. to 7h 00m p.m...	271.7	219.3	183.5	590.3	618.4
		7 00 p.m. 1 00 a.m...	259.0	187.1	144.3	506.3	991.9
		1 00 a.m. 7 10 a.m...	345.4	188.2	173.1	523.1	
135	C. R. Y. Feb. 8, 1906...	Rest, without food.					
		9h 15m a.m. to 11h 15m a.m...	59.4	58.7	51.8	173.3	194.4
136	F. G. B. Oct. 23, 1905..	Rest, with food.					
		5h 46m p.m. to 7h 51m p.m...	81.7	75.8	70.0	214.6	215.2
		7 51 p.m. 9 46 p.m...	83.3	76.9	57.4	211.1	183.8
		Total, 4h 00m	165.0	152.7	127.4	425.7	399.0

[1] Correction has been made here for heat from urine voided during the experiment.

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104–183*—Continued.

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
137	A. H. M. Nov. 13-14, '05.	Rest, with food.					
		$5^h 00^m$ p.m. to $7^h 00^m$ p.m...	74.1	67.0	55.5	209.5	196.7
		7 00 p.m. 9 00 p.m...	79.9	60.9	61.3	203.4	....
		9 00 p.m. 11 00 p.m...	63.9	47.6	47.6	175.4	....
		11 00 p.m. 1 00 a.m...	71.8	43.0	44.3	150.7	....
		1 00 a.m. 3 00 a.m...	65.1	34.8	40.3	109.0	....
		3 00 a.m. 5 00 a.m...	61.5	40.1	39.6	110.3	....
		5 00 a.m. 7 00 a.m...	62.3	45.5	50.7	112.9	....
		7 00 a.m. 9 00 a.m...	66.0	71.8	73.1	165.1	....
		9 00 a.m. 11 00 a.m...	71.5	59.3	52.6	170.6	178.4
		11 00 a.m. 12 15 p.m...	39.0	30.4	25.7	101.9	102.3
138	A. H. M. Jan. 29, 1906..	Lying awake, with food. $9^h 11^m$ a.m. to $12^h 11^m$ p.m...	89.6	82.2	64.3	204.2	211.6
		Intermediate period.					
		Sitting, eating. $12^h 11^m$ p.m. to $1^h 25^m$ p.m...	47.6	47.1	....	146.9	[1] 155.7
		Sitting. $1^h 25^m$ p.m. to $4^h 25^m$ p.m...	91.5	98.1	75.5	293.6	282.5
139	A. H. M. Jan. 30, 1906..	Standing, with food. $9^h 45^m$ a.m. to $12^h 45^m$ p.m...	94.1	101.4	74.3	267.6	253.1
		Intermediate period.					
		Sitting, eating. $12^h 45^m$ p.m. to $3^h 15^m$ p.m...	74.3	81.8	....	158.2	[2] 166.4
		Lying awake. $3^h 15^m$ p.m. to $6^h 15^m$ p.m...	99.4	94.1	75.3	249.6	257.3
140	A. H. M. Jan. 31, 1906..	Lying awake, with food. $9^h 45^m$ a.m. to $12^h 45^m$ p.m...	89.8	74.2	53.9	...	....
		Sitting. $12^h 45^m$ p.m. to $3^h 45^m$ p.m...	84.7	82.4	70.7	292.4	[1] 285.0
141	A. H. M. Feb. 14, 1906..	Rest, without food.					
		$9^h 00^m$ a.m. to $11^h 00^m$ a.m...	53.3	49.6	40.1	159.0	162.6
		11 00 a.m. 1 00 p.m...	48.6	43.8	34.6	154.0	146.0
		1 00 p.m. 3 00 p.m...	45.0	44.4	42.5	143.7	131.3
		3 00 p.m. 5 00 p.m...	44.0	46.4	39.9	140.9	137.5
		Total, $8^h 00^m$	190.9	184.2	157.1	597.6	577.4
142	A. H. M. Mar. 26, 1906..	Food aperture, without food.					
		$8^h 35^m$ a.m. to $10^h 35^m$ a.m...	61.6	57.8	52.7	190.0	186.8
		10 35 a.m. 12 35 p.m...	62.8	58.4	55.2	185.9	184.4
		12 35 p.m. 2 35 p.m...	63.8	60.5	60.6	188.0	185.4
		2 35 p.m. 4 35 p.m...	63.3	58.7	54.8	186.6	186.8
		Total, $8^h 00^m$	251.5	235.4	223.3	750.5	743.4
143	A. H. M. Apr. 2, 1906...	Sitting, with food. $2^h 57^m$ p.m. to $4^h 57^m$ p.m...	54.9	50.9	38.6	156.4	147.3
		Standing. $4^h 57^m$ p.m. to $6^h 57^m$ p.m...	59.2	59.0	47.4	163.3	146.5
144	A. H. M. Apr. 5, 1906...	Sitting, with food. $2^h 30^m$ p.m. to $4^h 30^m$ p.m...	51.2	46.1	43.0	145.3	144.6
		Standing. $4^h 30^m$ p.m. to $6^h 30^m$ p.m...	56.4	57.0	52.3	160.0	163.7
145	H. A. Nov. 14-15, '05	Rest, with food.					
		$3^h 00^m$ p.m. to $5^h 00^m$ p.m...	76.8	76.7	67.3	195.4	189.6
		5 00 p.m. 7 00 p.m...	79.2	74.3	69.4	211.9	224.8
		7 00 p.m. 9 00 p.m...	79.0	69.9	65.8	210.4	200.2
		9 00 p.m. 11 00 p.m...	67.1	59.0	50.7	198.8	186.9
		11 00 p.m. 1 00 a.m...	70.3	53.4	55.5	171.3	179.9
		1 00 a.m. 3 00 a.m...	77.2	50.6	47.8	147.3	155.3
		3 00 a.m. 5 00 a.m...	99.7	54.8	....	169.9	168.9
		5 00 a.m. 7 00 a.m...	106.5	59.5	55.5	169.1	158.4
		7 00 a.m. 9 00 a.m...	107.4	77.0	80.0	189.0	169.2
		9 00 a.m. 11 00 a.m...	103.3	57.2	59.9	157.8	165.5

[1] No correction has been made for heat possibly liberated from bed and bedding.
[2] No correction has been made for heat possibly stored in bed and bedding.

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104–183*—Continued.

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
146	D. W.	Rest, with food.					
	Jan. 14, 1906..	7^{h} 00^{m} a.m. to 9^{h} 00^{m} a.m...	73.7	87.4	95.7	217.6	268.3
		9 00 a.m. 11 00 a.m...	72.0	65.3	48.9	189.6	191.6
		11 00 a.m. 1 00 p.m...	82.4	62.4	56.7	188.2	178.3
		Total, 6^{h} 00^{m}	228.1	215.1	201.3	595.4	638.2
147	A. L. L.	Rest, without food.					
	Feb. 9, 1906...	9^{h} 00^{m} a.m. to 11^{h} 00^{m} a.m...	77.3	47.0	35.6	169.2	162.0
		11 00 a.m. 1 00 p.m...	64.5	47.2	44.1	150.9	144.6
		1 00 p.m. 3 00 p.m...	57.4	45.2	38.5	141.5	141.8
		3 00 p.m. 5 00 p.m...	54.8	47.4	44.0	137.4	146.8
		Total, 8^{h} 00^{m}	254.0	186.8	162.2	599.0	595.2
148	A. L. L.	Food aperture, without food.					
	Mar. 20, 1906...	9^{h} 10^{m} a.m. to 11^{h} 10^{m} a.m...	70.3	61.0	43.5	191.0	183.7
		11 10 a.m. 1 10 p.m...	64.8	57.7	50.9	170.3	163.9
		1 10 p.m. 3 10 p.m...	61.8	57.1	54.1	183.8	180.5
		3 10 p.m. 5 10 p.m...	55.7	55.0	50.6	172.2	173.7
		Total, 8^{h} 00^{m}	252.6	230.8	199.1	717.3	701.8
149	A. L. L.	Sitting, with food.					
	Apr. 3, 1906...	8^{h} 40^{m} a.m. to 10^{h} 40^{m} a.m...	56.1	48.4	39.4	154.5	147.6
		10 40 a.m. 12 40 p.m...	55.2	49.6	47.2	144.2	147.0
		Standing.					
		4^{h} 40^{m} a.m. to 6^{h} 40^{m} p.m...	58.6	52.2	51.2	176.9	197.1
150	H. R. D.	Rest, without food.					
	Feb. 10, 1906..	9^{h} 15^{m} a.m. to 11^{h} 15^{m} a.m...	50.3	48.4	38.5	159.0	149.5
		11 15 a.m. 1 15 p.m...	46.2	47.6	40.3	144.7	144.0
		1 15 p.m. 3 15 p.m...	42.8	44.8	40.3	140.6	141.3
		3 15 p.m. 5 15 p.m...	42.7	47.1	43.7	140.9	137.3
		Total, 8^{h} 00^{m}	182.0	187.9	162.8	585.2	572.1
151	H. R. D.	Food aperture, without food.					
	Mar. 24, 1906..	8^{h} 40^{m} a.m. to 10^{h} 40^{m} a.m...	53.4	52.7	51.1	165.9	161.0
		10 40 a.m. 12 40 p.m...	50.1	53.0	47.5	163.0	154.5
		12 40 p.m. 2 40 p.m...	50.2	56.0	57.1	160.4	163.3
		2 40 p.m. 4 40 p.m...	51.7	53.4	69.7	168.0	172.7
		Total, 8^{h} 00^{m}	205.4	215.1	225.4	657.3	651.5
152	H. R. D.	Sitting, with food.					
	Mar. 31, 1906.	2^{h} 45^{m} p.m. to 4^{h} 45^{m} p.m...	50.8	54.9	41.9	160.9	146.0
		Standing.					
		4^{h} 45^{m} p.m. to 6^{h} 45^{m} p.m...	50.4	50.4	37.8	164.2	172.7
		Rest, without food.					
153	H. R. D.	Lying asleep.					
	May 18, 1906..	1^{h} 10^{m} a.m. to 3^{h} 10^{m} a.m...	50.1	40.7	36.2	124.4	117.1
		3 10 a.m. 5 10 a.m...	46.1	44.4	41.8	124.7	118.6
		5 10 a.m. 7 10 a.m...	44.8	44.6	36.9	125.4	143.2
		Total, 6^{h} 00^{m}	141.0	129.7	114.9	374.5	378.9
		Lying awake.					
		7^{h} 10^{m} a.m. to 9^{h} 10^{m} a.m...	51.7	51.3	51.2	145.2	149.3
		9 10 a.m. 11 10 a.m...	44.6	45.1	34.6	138.5	135.8
		11 10 a.m. 1 10 p.m...	48.7	49.9	42.7	149.3	144.1
		Total, 6^{h} 00^{m}	146.0	146.3	128.5	433.0	429.2
154	J. H. K.	With food, walking.					
	Apr. 17, 1906..	2^{h} 00^{m} p.m. to 4^{h} 00^{m} p.m...	78.4	64.3	58.9	192.3	185.9
		4 00 p.m. 6 00 p.m...	68.2	61.3	53.0	183.3	199.0
		Total, 4^{h} 00^{m}	146.6	125.6	111.9	375.6	384.9
		Lying asleep.					
		7^{h} 15^{m} p.m. to 9^{h} 15^{m} p.m...	56.2	42.7	36.6	129.0	123.5
		Lying awake.					
		9^{h} 15^{m} p.m. to 11^{h} 15^{m} p.m...	74.0	49.1	43.8	161.5	151.8

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104–183*—Continued.

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
155	H. C. K. May 3, 1906...	Rest, without food.					
		$9^h 05^m$ a.m. to $11^h 05^m$ a.m...	80.1	51.9	47.3	179.5	175.3
		11 05 a.m. 1 05 p.m...	64.6	47.4	42.1	154.7	160.6
		1 05 p.m. 3 05 p.m...	62.9	52.1	51.4	158.4	152.4
		3 05 p.m. 5 05 p.m...	60.1	53.1	47.0	153.0	166.8
		Total, $8^h 00^m$	267.7	204.5	187.8	645.6	655.1
156	H. C. K. May 16, 1906..	Rest, without food. Lying asleep.					
		$1^h 10^m$ a.m. to $3^h 10^m$ a.m...	63.0	50.0	50.7	149.2	156.7
		3 10 a.m. 5 10 a.m...	61.7	47.0	30.3	144.1	146.9
		5 10 a.m. 7 10 a.m...	62.5	55.6	60.3	172.2	171.5
		Total, $6^h 00^m$	187.2	152.6	141.3	465.5	475.1
		Lying awake.					
		$7^h 10^m$ a.m. to $9^h 10^m$ a.m...	59.2	50.9	44.3	170.8	164.5
		9 10 a.m. 11 10 a.m...	60.7	57.4	50.0	171.4	166.7
		11 10 a.m. 1 10 p.m...	61.4	56.7	49.8	169.8	171.4
		Total, $6^h 00^m$	181.3	165.0	144.1	512.0	502.6
157	H. C. K. May 23, 1906..	Rest, without food. Lying asleep.					
		$1^h 30^m$ a.m. to $3^h 30^m$ a.m...	58.9	44.5	40.5	126.0	120.1
		3 30 a.m. 5 30 a.m...	61.6	45.1	37.9	128.8	150.8
		5 30 a.m. 7 30 a.m...	63.7	55.8	55.7	164.0	167.7
		Total, $6^h 00^m$	184.2	145.4	134.1	418.8	438.6
		Lying awake.					
		$7^h 30^m$ a.m. to $9^h 30^m$ a.m...	63.9	52.8	44.7	172.1	171.7
		9 30 a.m, 11 30 a.m...	57.0	52.3	48.1	168.8	166.8
		11 30 a.m. 1 30 p.m...	62.2	54.1	43.0	164.4	166.7
		Total, $6^h 00^m$	183.1	159.2	135.8	505.3	505.2
158	H. G. Feb. 24, 1905..	Rest, with food.					
		$9^h 15^m$ a.m. to $10^h 45^m$ a.m...	43.1	45.1	....	116.5	....
		10 45 a.m. 12 15 p.m...	45.9	38.5	29.8	116.1	....
		Total, $3^h 00^m$	89.0	83.6	....	232.6	233.2
		Undressing and weighing. $12^h 15^m$ p.m. to $1^h 15^m$ p.m...	30.6	36.4	25.3	86.2	83.0
159	H. L. W. Feb. 24, 1905..	Rest, with food.					
		$2^h 22^m$ p.m. to $3^h 52^m$ p.m...	60.4	48.9	40.5	155.2	....
		3 52 p.m. 5 22 p.m...	60.6	40.6	33.8	148.6	....
		Total, $3^h 00^m$	121.0	89.5	74.3	303.8	284.6
		Undressing and weighing. $5^h 22^m$ p.m. to $6^h 22^m$ p.m...	38.2	38.4	32.6	108.0	120.4
160	F. E. R. Feb. 25, 1905..	Rest, with food.					
		$9^h 00^m$ a.m. to $10^h 30^m$ a.m...	68.2	43.6	34.4	163.7	....
		10 30 a.m. 12 00 noon.	56.4	42.1	30.7	137.6	....
		Total, $3^h 00^m$	124.6	85.7	65.1	301.3	295.6
		Undressing and weighing. $12^h 00^m$ noon to $1^h 00^m$ p.m...	39.0	48.2	42.3	110.5	117.9
161	F. N. C. Feb. 25, 1905..	Rest, with food.					
		$2^h 00^m$ p.m. to $3^h 30^m$ p.m...	48.6	48.3	42.7	158.2	....
		3 30 p.m. 5 00 p.m...	47.7	48.8	....	147.2	....
		Total, $3^h 00^m$	96.3	97.1	....	305.4	295.4
		Undressing and weighing. $5^h 00^m$ p.m. to $6^h 00^m$ p.m...	31.0	43.5	....	115.2	125.9

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104–183*—Continued.

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
162	H. C. A. Feb. 27, 1905..	Rest, with food.					
		$8^h\ 52^m$ a.m. to $10^h\ 22^m$ a.m...	42.8	48.6	36.8	162.4	....
		10 22 a.m. 11 52 a.m...	39.7	43.0	35.9	135.8	....
		Total, $3^h\ 00^m$	82.5	91.6	72.7	298.2	282.8
		Undressing and weighing. $11^h\ 52^m$ a.m. to $12^h\ 52^m$ p.m...	24.0	36.9	26.8	98.4	106.4
163	N. M. P. Feb. 27, 1905..	Rest, with food.					
		$2^h\ 00^m$ p.m. to $3^h\ 30^m$ p.m...	50.9	54.0	43.8	180.1	....
		3 30 p.m. 5 00 p.m...	56.7	58.6	46.3	174.8	....
		Total, $3^h\ 00^m$	107.6	112.6	90.1	354.9	343.2
		Undressing and weighing. $5^h\ 00^m$ p.m. to $6^h\ 00^m$ p.m...	36.8	48.1	38.0	118.0	117.3
164	J. A. R. Feb. 28, 1905..	Rest, with food.					
		$9^h\ 15^m$ a.m. to $10^h\ 45^m$ a.m...	48.6	44.1	32.2	154.4	....
		10 45 a.m. 12 15 p.m...	42.4	40.4	30.0	133.0	....
		Total, $3^h\ 00^m$	91.0	84.5	62.2	287.4	269.2
		Undressing and weighing. $12^h\ 15^m$ p.m. to $1^h\ 15^m$ p.m...	33.7	36.9	23.4	102.1	104.7
165	H. D. A. Feb. 28, 1905..	Rest, with food.					
		$2^h\ 03^m$ p.m. to $3^h\ 33^m$ p.m...	61.9	58.0	55.7	175.7	....
		3 33 p.m. 5 03 p.m...	69.0	54.0	43.6	165.3	....
		Total, $3^h\ 00^m$	130.9	112.0	99.3	341.0	323.0
		Undressing and weighing. $5^h\ 03^m$ p.m. to $6^h\ 03^m$ p.m...	38.2	45.2	29.4	127.0	129.1
166	H. L. K. Mar. 1, 1905...	Rest, with food.					
		$8^h\ 54^m$ a.m. to $10^h\ 24^m$ a.m...	48.8	45.5	37.3	143.8	....
		10 24 a.m. 11 54 a.m...	43.9	42.3	34.5	128.1	....
		Total, $3^h\ 00^m$	92.7	87.8	71.8	271.9	280.4
		Undressing and weighing. $11^h\ 54^m$ a.m. to $12^h\ 54^m$ p.m...	35.1	44.5	27.1	111.4	116.7
167	A. M. Mar. 1, 1905...	Rest, with food.					
		$1^h\ 48^m$ p.m. to $3^h\ 18^m$ p.m...	58.6	51.5	40.7	160.3	....
		3 18 p.m. 4 48 p.m...	59.4	53.6	41.3	151.5	....
		Total, $3^h\ 00^m$	118.0	105.1	82.0	311.8	293.8
		Undressing and weighing. $4^h\ 48^m$ p.m. to $5^h\ 48^m$ p.m...	35.7	53.1	48.2	124.4	137.4
168	D. R. F. Mar. 2, 1905...	Rest, with food.					
		$8^h\ 46^m$ a.m. to $10^h\ 16^m$ a.m...	46.7	59.6	43.3	144.9	....
		10 16 a.m. 11 46 a.m...	44.4	45.2	35.0	138.7	....
		Total, $3^h\ 00^m$	91.1	104.8	78.3	283.6	272.7
		Undressing and weighing. $11^h\ 46^m$ a.m. to $12^h\ 46^m$ p.m...	29.4	31.4	29.4	109.1	115.3
169	J. N. T. Mar. 2, 1905...	Rest, with food.					
		$2^h\ 16^m$ p.m. to $3^h\ 46^m$ p.m...	49.1	56.0	41.8	180.7	....
		3 46 p.m. 5 16 p.m...	56.8	52.7	41.1	164.7	....
		Total, $3^h\ 00^m$	105.9	108.7	82.9	345.4	313.7
		Undressing and weighing. $5^h\ 16^m$ p.m. to $6^h\ 16^m$ p.m...	39.7	49.9	32.7	123.6	133.6

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104–183*—Continued.

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
170	C. A. R. Mar. 18, 1905..	Rest, with food.					
		8h 57m a.m. to 10h 27m a.m...	60.0	55.1	41.9	160.9	....
		10 27 a.m. 11 57 a.m...	58.5	46.9	36.2	146.9	....
		Total, 3h 00m	118.5	102.0	78.1	307.8	297.4
		Undressing and weighing. 11h 57m a.m. to 12h 58m p.m...	33.7	44.4	33.1	109.1	120.3
171	A. G. Mar. 18, 1905..	Rest, with food.					
		2h 00m p.m. to 3h 30m p.m...	65.5	58.3	44.2	173.0	....
		3 30 p.m. 5 00 p.m...	65.3	51.9	42.6	153.6	....
		Total, 3h 00m	130.8	110.2	86.8	326.6	318.1
		Undressing and weighing. 5h 00m p.m. to 6h 00m p.m...	39.3	48.6	38.6	122.3	131.2
172	G. G. R. Mar. 20, 1905..	Rest, with food.					
		8h 53m a.m. to 10h 23m a.m...	66.4	61.1	....	175.3	....
		10 23 a.m. 11 53 a.m...	66.2	55.0	...	164.2	....
		Total, 3h 00m	132.6	116.1	....	339.5	332.6
		Undressing and weighing. 11h 53m a.m. to 12h 53m p.m...	46.7	49.2	40.0	119.8	123.2
173	J. V. C. Mar. 21, 1905..	Rest, with food.					
		8h 48m a.m. to 10h 18m a.m...	66.9	52.8	42.4	165.2	....
		10 18 a.m. 11 48 a.m...	63.2	44.8	31.6	156.0	....
		Total, 3h 00m	130.1	97.6	74.0	321.2	314.8
		Undressing and weighing. 11h 48m a.m. to 12h 48m p.m...	39.4	39.1	29.8	105.6	106.4
174	E. M. S. Mar. 21, 1905..	Rest, with food.					
		2h 16m p.m. to 3h 46m p.m...	63.8	48.6	40.2	178.2	....
		3 46 p.m. 5 16 p.m...	60.5	43.0	32.7	150.4	....
		Total, 3h 00m	124.3	91.6	72.9	328.6	320.5
		Undressing and weighing. 5h 16m p.m. to 6h 16m p.m...	39.8	44.4	35.3	106.8	112.4
175	G. E. H. Mar. 22, 1905..	Rest, with food.					
		9h 07m a.m. to 10h 37m a.m...	53.1	41.5	32.0	132.9	....
		10 37 a.m. 12 07 p.m...	50.4	36.8	29.8	119.7	....
		Total, 3h 00m	103.5	78.3	61.8	252.6	247.7
		Undressing and weighing. 12h 07m p.m. to 1h 07m p.m...	26.8	38.8	52.4	91.5	....
176	G. H. H. Mar. 23, 1905..	Rest, with food.					
		8h 47m a.m. to 9h 56m a.m...	42.4	39.5	31.1	103.9	....
		9 56 a.m. 11 56 a.m...	72.9	60.0	59.1	176.0	....
		Total, 3h 09m	115.3	99.5	90.2	279.9	280.3
		Undressing and weighing. 11h 56m a.m. to 12h 56m p.m...	36.3	41.8	32.8	97.9	107.4
177	J. W. H. Mar. 23, 1905..	Rest, with food.					
		1h 40m p.m. to 3h 10m p.m...	69.2	61.9	51.9	170.4	....
		3 10 p.m. 4 40 p.m...	73.3	58.5	45.2	176.8	....
		Total, 3h 00m	142.5	120.4	97.1	347.2	343.5
		Undressing and weighing. 4h 40m p.m. to 5h 40m p.m...	43.7	48.5	39.8	121.4	131.1

TABLE 44.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat eliminated and produced—Metabolism experiments Nos. 104–183*—Continued.

Experiment No.	Subject and date.	Kind of experiment and period.	Water vaporized.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat eliminated.	Heat produced.
			Grams.	*Grams.*	*Grams.*	*Cals.*	*Cals.*
178	G. W. S. Mar. 25, 1905..	Rest, with food.					
		9h 10m a.m. to 10h 40m a.m...	57.2	42.7	39.0	124.9	....
		10 40 a.m. 12 10 p.m...	56.3	40.0	26.9	125.4	....
		Total, 3h 00m	113.5	82.7	65.9	250.3	253.5
		Undressing and weighing. 12h 10m p.m. to 1h 10m p.m...	36.8	36.7	30.4	96.3	101.2
179	C. F. S. June 16, 1905.	Rest, with food. 9h 32m a.m. to 12h 02m p.m...	117.5	62.5	47.7	183.2	182.6
180	C. F. S. June 21, 1905.	Rest, with food. 7h 10m p.m. to 9h 40m p.m...	121.2	71.5	55.6	223.8	176.7
181	G. E. B. June 22, 1905.	Rest, with food.					
		9h 18m a.m. to 10h 48m a.m...	69.9	33.5	34.1	87.5	77.9
		10 48 a.m. 12 18 p.m...	67.5	32.8	24.2	96.7	87.0
		Total, 3h 00m	137.4	66.3	58.3	184.2	164.9
182	G. E. B. June 23, 1905.	Rest, with food.					
		8h 54m a.m. to 10h 54m a.m...	104.9	43.2	38.1	141.8	117.5
		10 54 a.m. 12 54 p.m...	82.4	39.4	47.0	123.1	119.5
		Total, 4h 00m	187.3	82.6	85.1	264.9	237.0
183	G. E. B. June 24, 1905.	Rest, with food.					
		9h 02m a.m. to 11h 02m a.m...	82.4	51.8	29.4	124.9	109.5
		11 02 a.m. 1 02 p.m...	74.8	41.0	38.3	119.1	118.0
		Total, 4h 00m	157.2	92.8	67.7	244.0	227.5

PART 3. DISCUSSION OF RESULTS.

When we consider the chemical complexity of man's organism, the considerable differences in size, weight, and temperament, and the marked changes in diet and physical activity in the course of his daily life, it is difficult to imagine him as having a normal metabolism to which all metabolism measurements can be referred. No two people may be said to be alike even in physical appearance, and it is reasonable to suppose that, when all the factors of life are taken into consideration, this lack of similarity will be even more apparent. Different people would, therefore, be expected, *a priori,* to show marked differences in metabolism, and yet the collection of statistics regarding the metabolic functions of individuals approximating uniformity in size, weight, physical activity, and general development will give results of distinct value and interest. It is obvious that for general use the results obtained from a careful study of one or two individuals can have but little bearing on the study of the normal requirements of man in general, and hence it is important to make studies of a large number of individuals and eliminate the personal equation in order to draw satisfactory deductions with regard to the normal metabolism of man. It is, furthermore, important to group individuals according to size, weight, or physical development, and note if the averages drawn from the results indicate merely the "might of average figures" or if they truly represent the average metabolism of individuals of a stated physical characteristic.

Comparison of Methods.

In order to study a large number of individuals in this way and with the proper degree of care, special apparatus is necessary. The urine can be readily collected and analyzed, and the products which are excreted determined, without particular difficulty; consequently, we find records of the protein metabolism of a large number of individuals. The study of the total metabolism, however, requires much more elaborate apparatus, a need which has been supplied by the respiration apparatus, and the experiments in respiration thus far made can be placed in two important groups according to the two different methods employed. By one method the metabolism of a large number of individuals is studied simultaneously; by the other, the individuals are studied separately, and thus any differences due to the personal equation may be carefully noted.

Group method.—The first method is that which has been employed with such signal success by Sondén and Tigerstedt.[1] By this method of experi-

[1] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, 6, p. 1.

menting, a number of individuals (6 to 10 or more) were placed in a large respiration chamber and the combined carbon-dioxide excretion of the group of individuals was studied, there being no attempt made to distinguish the differences in the metabolism of individuals. This method gives a true average of the group. Furthermore, a number of different groups were studied, thus giving an idea regarding the constancy of groups of individuals, and it was inferred that if groups similar in physical constitution, muscular activity, etc., gave constant results, individuals would likewise give constant results.

Sondén and Tigerstedt recognized the importance of securing a value which would be as truly representative as possible for the one factor of metabolism they were measuring, namely, carbon dioxide, and devoted special attention to the determination of this factor with the greatest degree of exactness. By means of a modified Pettersson apparatus, Sondén [1] was able to secure results that were far more accurate than any previously obtained. It is certain, therefore, that the results secured with this apparatus do represent with great exactness the carbon-dioxide production of groups of individuals under the conditions stated in the protocols.

Individual subject method.—While the first method has been used almost exclusively by Sondén and Tigerstedt, the second method has been adopted by a large number of investigators, especially when using various forms of mouthpieces or nosepieces for collecting the products of respiration. In a large number of their experiments, only carbon dioxide has been determined, but in those made by Speck, and Zuntz and his school, and more recently by Chauveau and Tissot, oxygen has likewise been determined. To the second class, also, belong the series of experiments with the respiration calorimeter which has been made in the laboratory of Wesleyan University. In the earlier experiments not only was the carbon dioxide determined but likewise the water-vapor and the heat elimination. More recently, all four factors of the total metabolism—the carbon-dioxide output, oxygen intake, water-vapor elimination, and heat production—have been simultaneously determined, the multiplication of determined factors thus rendering the whole study more valuable. These experiments were much more time-consuming and laborious than those made with any other apparatus. As but one individual could be studied at a time, it was necessary, of course, to make a large number of experiments and the respiration chamber was in more or less constant use.

Possible comparison of results by the two methods.—It is possible, therefore, to compare the average results of respiration-calorimeter experiments on a large number of different individuals with those obtained by Sondén and Tigerstedt in their group experiments. Unfortunately, the investigations with the respiration calorimeter could not be extended to cover as large a group of individuals of different ages as did those of the Scandinavian investigators.

[1] Sondén, Zeitschr. f. Instrumentenkunde, 1889, 9, p. 472.

It is therefore highly important that further investigations with the respiration calorimeter be made on individuals of different body-weight, sex, age, etc., to supplement the measurement of the carbon-dioxide production by the still more important measurement of the factors, oxygen consumption and heat production.

A comparison of the researches thus far made by the two methods is of unusual interest. The research of Sondén and Tigerstedt, undertaken primarily on the grounds of hygiene in connection with school ventilation, is one of the most important contributions to our knowledge of the carbon-dioxide excretion that has ever been made. Unquestionably the results of the Scandinavian investigators can be considered as normal for the conditions obtaining in their experiments. The experiments were sufficiently extended in nature, and a large enough number of individuals was employed to render it highly probable that the results indicate a true average. Our experiments were therefore not made with any idea of repeating or verifying the observations of the Scandinavian investigators on carbon-dioxide production, but were carried out in connection with a study of the total metabolism of individuals. The carbon-dioxide values are of unusual interest, not only for comparison with the measurements of the other factors, but likewise for comparison with and confirmation of the results obtained by Sondén and Tigerstedt.

It is obvious that in experiments on man, to secure results nearest normal, the conditions should approximate the ordinary daily activity and daily bodily conditions; hence, however valuable the researches with special nosepieces or mouthpieces may be for comparison and for other purposes, as a basis for deducing the normal metabolism of man, they can not have the value of those made in connection with experiments where the respiration is free. Consequently, in a study of normal metabolism the experiments in this laboratory must of necessity be compared with those made by Sondén and Tigerstedt, since in both sets of experiments the respiration was free and untrammelled.

Basis of comparison for experiments with special appliances.—It is also important to compare the results obtained by the respiration-chamber method with those obtained by the various writers using mouthpieces and nosepieces. Beginning with the early experiments of Smith[1] and concluding with the more recent researches of Zuntz, we have a long series of most interesting results, which throw light upon the carbon-dioxide production and the oxygen consumption of men lying quietly breathing through special mouthpieces and nosepieces as compared with men sitting in an upright position and breathing normally the air of a special room or chamber. Such comparisons must have value in determining the differences, if any, between the two forms of experimenting, and for this purpose similarity of body-position is therefore desirable. Unfortunately, by far the larger number of experiments made with the respira-

[1] Smith, Philosophical Transactions, 1859, 149, p. 681.

tion chamber has been made with subjects sitting upright, while practically all the experiments in which special breathing appliances were used, especially those giving the most scientifically accurate results, have been made with subjects lying down.

For the purpose of this report, namely, the study of the normal metabolism of man, the earlier results, *i. e.*, with special nose or mouth appliance, are not satisfactory from the very fact that the subjects were lying down awake, whereas, with man, the period of lying awake is ordinarily not very long. It must be admitted that the confinement within a respiration chamber is not wholly normal, but the number of hours spent per day in sitting awake is much greater normally than that in lying awake, and hence the values obtained with subjects sitting upright in the respiration chambers do throw light upon the metabolism of man when not doing extraneous muscular work, such as walking, or muscular work in the course of a trade or profession.

DUPLICATION OF RESULTS IN INDIVIDUAL METABOLISM.

In publishing the results of the experiments here reported, our primary object is to present a mass of material that can be used for drawing deductions regarding the normal gross metabolism of man, but, before discussing this subject, it is important to see whether there is constancy with the same individual under like conditions of muscular activity and diet. As a result of a number of preliminary observations it has been found that changes in muscular activity, body condition, diet, etc., may produce noticeable alterations in the total metabolism, and hence, these experiments have been made with as many individuals as possible and under like conditions. Frequently duplicate or triplicate experiments were made with the same subject. The statistical details have been given in the preceding section and it is now proposed, in the first place, to demonstrate to what extent one can rely upon duplicate experiments with the same individual.

The physiological processes are so complex that it might be questioned whether duplication of results can be obtained, even with the same individual, for when it is considered that metabolism includes the operation of a large number of forces, with a most complex chemical constitution involved in each transformation, it should not be at all surprising to find a lack of constancy from day to day. If the results in experiments with one subject vary considerably from time to time, and precautions have been taken to secure uniform conditions, obviously, the average of the various results obtained can not be taken as representing the normal metabolism of that individual. If, on the contrary, the metabolism remains constant, the average for this individual can be taken as typical and his metabolism can, with perfect propriety, be compared with that of other subjects under similar conditions.

CONSTANCY IN METABOLISM AS REPORTED BY EARLIER WRITERS.

From an examination of the earlier literature it may be seen that in the researches of Andral and Gavarret,[1] and in the simultaneously published researches of Scharling[2] there are a number of experiments, particularly in the first case, which may reasonably be considered as duplicates. Thus, Andral and Gavarret find that the same subject exhaled in 1 hour amounts of carbon dioxide represented by from 10.4 to 11.2 grams of carbon. This was the sixth experiment with this subject, the average of all the experiments being 10.7 grams. With a second subject, the amounts of carbon per hour varied from 8.5 grams to 8.8 grams in 4 experiments. Scharling's duplicate results are not quite so evident, but on examining table 1 on page 492, and table 2 on page 493 of his original article, it is seen that the amount of carbon per hour was reasonably constant with the same conditions of muscular activity and of ingestion of food.

Assuming that the carbon dioxide is a true index of the total metabolism, these researches in themselves would indicate that the metabolism was constant with the same individual, but we now know that the carbon dioxide is but imperfectly indicative of the total metabolism as the amount of carbon dioxide may vary considerably, depending upon the character of the diet. Since, however, the heat production in general varies more nearly as the oxygen intake, a much more satisfactory index is the accurate measurement of the oxygen consumption and fortunately, as a result of the work of Zuntz and his co-workers, we have much material on this point, particularly with regard to the total metabolism of men at rest, breathing through special appliances, although in experiments of but a few minutes' duration. The experiments prior to the researches of Speck and Zuntz throw very little light upon the accurate determination of oxygen with man in experiments continuing two or more hours. The heat measurements are also lacking in a large majority of experiments. It appears, therefore, that the experiments at Wesleyan University furnish data regarding the largest number of individuals in which all these three factors of metabolism, carbon-dioxide excretion, oxygen consumption, and heat production were studied, and for this reason it is especially advantageous to note the constancy or lack of constancy in the results obtained.

DUPLICATION IN SERIES HERE PUBLISHED.

Accordingly, the results of certain of these experiments have been included in a large table (table 45) so as to show comparable averages of carbon-dioxide output, oxygen intake, and heat production per hour with any particular individual. Data for 14 different subjects are presented and a total of 48 experiments have been included in the enumeration, which, so far as numbers go, makes reasonably sound such deductions as may be drawn from the comparisons.

[1] Andral and Gavarret, Ann. de Chim. et de Phys., 1843, ser. 3, 8, p. 129.
[2] Scharling, Ann. de Chim. et de Phys., 1843, ser. 3, 8, p. 478; also in the Ann. der Chem. und Pharm., 1843, 45, p. 214.

In collecting the experiments in this table, only those that are strictly comparable as regards the muscular activity, time of day, digestion, etc., are brought together, and certain of the experiments presented in the preceding section are admirably suited for a discussion of constancy in metabolism. It has been deemed advisable likewise to include previously published experiments with the same individual so far as the conditions are equally comparable with the conditions of those already included. Many of these earlier experiments were designed for an entirely different purpose and only sections are used for comparison here; thus, as regards the sleeping periods the published experiments were inanition periods of 24 hours, with a preliminary night following the ingestion of food. These earlier results have given an added value, for they show in several instances, at least, the metabolism of the same individual under like conditions with an interval of several months. The last three experiments presented in the table were made with a woman subject. In this collection of comparisons it is aimed to state the muscular activity, whether the subject was awake or asleep, with or without food, and the time of day, together with the carbon dioxide excreted, the oxygen absorption, and the heat production per hour. While, for the most part, the duplicate experiments covered the same period of the day, sometimes this was not exactly the case, but such instances, because of the muscular activity usual inside the respiration chamber, may be considered as not affecting the respective comparisons. The table is not designed in any way to throw light upon the comparative metabolism of different individuals or for the study of the differences in metabolism of the same individual under different conditions, but merely to show the constancy of metabolism in the same individual under similar conditions. The data are given only as average quantities per hour for the whole experiment, and for any further details one must refer to the statistics of the experiments.

An examination of the figures in this table shows that there is a striking uniformity of metabolism in the experiments with the same individual under like conditions of bodily activity. For example, it rarely happens that in two experiments with the same individual and a given condition, the carbon-dioxide excretion varies by more than 2 grams per hour, and in many instances the agreement is complete.

Similar uniformity is shown with regard to the oxygen consumption in different experiments with the same individual. As has been pointed out in many publications, the determination of oxygen is very difficult, and hence more reliance can be placed upon the greater accuracy and uniformity of the determinations of carbon dioxide. However, we believe that the oxygen determinations here given represent as truly as any values heretofore presented the oxygen consumption of individuals under the conditions obtaining in these experiments. The results show conclusively that with the same individual under like conditions of activity the oxygen consumption is relatively con-

TABLE 45.—*Carbon dioxide eliminated, oxygen absorbed, and heat produced in duplicate experiments.*

Subject.	Experiment number.	Activity.[1]	Period.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat produced.
				Grams.	*Grams.*	*Cals.*
B. F. D...	105	Rest awake	$7^h 00^m$ a.m. to $5^h 00^m$ p.m....	31.1	28.3	92
	[2] 59	........Do.........	7 00 a.m. 4 00 p.m....	31.0	27.7	98
B. F. D...	106	Rest awake	2 28 p.m. 4 58 p.m....	33.6	26.1	105
	107	........Do.........	2 44 p.m. 8 45 p.m....	34.6	28.8	101
	108	........Do.........	12 45 p.m. 6 45 p.m....	34.6	28.6	95
B. F. D...	104	Rest awake	7 00 a.m. 7 00 p.m....	38.6	29.4	110
	[3] 60	........Do.........	7 00 a.m. 7 00 p.m....	[7] 37.2	[7] 30.2	[7] 104
B. F. D...	105	Sleeping	1 00 a.m. 7 00 a.m....	24.5	20.7	70
	[2] 59	........Do.........	1 00 a.m. 7 00 a.m....	24.8	21.6	73
H. C. M...	114	Rest awake	9 56 a.m. 3 56 p.m....	38.7	30.7	112
	115	........Do.........	9 53 a.m. 3 53 p.m....	37.8	30.6	107
S. C. D....	116	Rest awake	9 16 a.m. 3 16 p.m....	34.2	28.9	98
	117	........Do.........	9 17 a.m. 3 17 p.m....	36.3	28.0	100
B. N.	118	Rest awake	9 44 a.m. 3 44 p.m....	31.6	26.4	91
	119	........Do.........	10 22 a.m. 4 22 p.m....	29.9	23.0	82
	120	........Do.........	10 30 a.m. 4 30 p.m....	30.6	24.5	86
W. H. L...	123	Rest awake	9 43 a.m. 3 43 p.m....	34.8	26.2	90
	124	........Do.........	9 07 a.m. 3 07 p.m....	34.6	26.3	93
R. A. M...	128	Rest awake	9 24 a.m. 3 24 p.m....	34.8	29.2	99
	129	........Do.........	9 42 a.m. 3 42 p.m....	34.8	28.2	99
H. L. K...	130	Rest awake	8 39 a.m. 12 39 p.m....	30.2	25.6	92
	166	........Do.........	8 54 a.m. 11 54 a.m....	29.3	23.9	93
	[4] 87, 88	........Do.........	9 00 a.m. 1 00 p.m....	[8] 28.5	[8] 23.9	[8] 90
	[5] 20	........Do.........	8 59 a.m. 11 59 a.m....	30.6	23.4	95
H. A. P...	131	Rest awake	9 44 a.m. 3 44 p.m....	29.2	22.9	85
	132	........Do.........	9 10 a.m. 3 10 p.m....	31.1	25.3	86
C. R. Y...	135	Rest awake	9 15 a.m. 11 15 a.m....	29.4	25.9	97
	[2] 80	........Do.........	9 00 a.m. 11 00 a.m....	29.4	22.0	89
C. R. Y...	134	Rest awake	1 00 p.m. 7 00 p.m....	36.6	30.6	103
	[4] 78	........Do.........	1 00 p.m. 7 00 p.m....	39.5	31.6	105
A. H. M..	141	Rest awake	9 00 a.m. 5 00 p.m....	23.0	19.6	72
	[2] 81	........Do.........	9 00 a.m. 5 00 p.m....	23.4	22.9	79
A. H. M..	143	Rest awake	2 57 p.m. 4 57 p.m....	25.5	19.3	74
	144	........Do.........	2 30 p.m. 4 30 p.m....	23.1	21.5	72
A. H. M..	137	Sleeping	1 00 a.m. 7 00 a.m....	20.1	21.8	55
	[2] 81	........Do.........	1 00 a.m. 7 00 a.m....	18.8	15.2	54
A. L. L...	147	Rest awake	9 00 a.m. 1 00 p.m....	23.6	19.9	77
	149	........Do.........	8 40 a.m. 12 40 p.m....	24.5	21.7	74
H. R. D..	153	Sleeping	1 10 a.m. 7 10 a.m....	21.6	19.1	63
	[2] 83	........Do.........	1 00 a.m. 7 00 a.m....	19.9	17.8	62
H. C. K...	156	Sleeping	1 10 a.m. 7 10 a.m....	25.4	23.6	79
	157	........Do.........	1 30 a.m. 7 30 a.m....	24.2	22.3	73
	[2] 82	........Do.........	1 00 a.m. 7 00 a.m....	25.0	20.2	69
H. C. K...	156	Lying awake ..	7 10 a.m. 1 10 p.m....	27.5	24.0	84
	157	........Do.........	7 30 a.m. 1 30 p.m....	26.5	22.6	84
G. E. B.[6]..	181	Rest awake	9 18 a.m. 12 18 p.m....	22.1	19.4	55
	182	........Do.........	8 54 a.m. 12 54 p.m....	20.7	21.3	59
	183	........Do.........	9 02 a.m. 1 02 p.m....	23.2	16.9	57

[1] The grouping is according to variations in diet as well as activity. Some of the groups give results during inanition.
[2] Benedict, Carnegie Institution of Washington Publication No. 77, 1907.
[3] Benedict and Milner, U. S. Dept. of Agr., Office of Exp. Stas. Bul. 175, 1907.
[4] Unpublished experiments.
[5] Benedict and Carpenter, U. S. Dept. of Agr., Office of Exp. Stas. Bul 208, 1909.
[6] Woman subject. [7] Average for 3 days. [8] Average for 4 days.

stant, not only from day to day, but also in experiments with an interval of several months.

In the results for heat production there is the concordance that one would expect after having observed the constancy of carbon-dioxide excretion and oxygen consumption. Differences of 10 calories are relatively uncommon; usually the agreement between duplicate experiments is 3 or 4 calories. These experiments show conclusively, therefore, that in conditions of rest, either with or without food, and likewise during sleep, the metabolism of the same individual is surprisingly constant from day to day.

With such constancy in metabolism under conditions of rest, it is to be regretted that special experiments have not been made to study the constancy during muscular work. No experiments on work or when the subject is exercising are here included, for it is very difficult to insure the exact amount of muscular activity in an experiment of this character unless a special form of ergometer is employed, such as was used in the previously published experiments on muscular work.

DUPLICATION IN EXPERIMENTS DURING MUSCULAR WORK.

A striking instance of constancy during work with a bicycle-ergometer has appeared in a previously published report on muscular work,[1] and although none of the new experiments presented in this publication deal with the question of muscular work, it is possible to refer briefly to the results there obtained. From those results it is seen that with the same individual, exercising the same amount, the metabolism is likewise remarkably constant. This is particularly well shown in the table on page 31 of that report, where the results of the experiments with the professional athlete are calculated to the per hour basis. It is there seen that experiments on the bicycle-ergometer, with the same amount of work per hour, were made on October 22, 1904, and January 23, 1905, two experiments being made on the latter date. In these three experiments, the heat equivalent of muscular work performed varied from 114 to 116 calories per hour. The total heat production varied from 608 to 626 calories, and the carbon-dioxide production from 208 to 231 grams. The oxygen consumption was determined in only two of the experiments, the amount in one being 183 grams and in the other 175 grams per hour. Considering the large amount of mechanical work performed, with the enormous heat production of over 600 calories per hour, the agreement between these duplicate experiments is certainly striking. All the evidence furnished by the experiments with the respiration calorimeter therefore substantiates fully the hypothesis that with the same individual under similar conditions of bodily activity and diet the metabolism is relatively constant.

In the following discussion of the results of the experiments in this report, special emphasis is laid upon the experimental period from 1 a. m. to 7 a. m.,

[1] Benedict and Carpenter, U. S. Dept. Agr., Office Expt. Stas. Bul. 208, 1909.

when the subjects were lying quietly at rest, and for the most part were in profound sleep. Since the bodily activities were at the lowest point in this period, it is highly probable that experiments with the same individual, or experiments with different individuals can better be compared during this period than during any other period in the day. Consequently, it seems advisable to have two separate discussions for each factor of metabolism, one, for the metabolism during sleep, and the other, the metabolism when awake. This method of treating the subject is followed in all the discussions in this report, with the exception of the discussion of the water vaporized from lungs and skin.

CHANGES IN BODY-WEIGHT.

To the layman one of the most obvious indices of the value of a given diet would be the changes in body-weight, for it is commonly believed that any increase in body-weight indicates ample, if not excessive, nourishment, and that a decrease is evidence of insufficient nourishment. For experiments of long duration, such as are commonly made on domestic animals when feeding or fattening for market, this is a remarkably good index. With man, however, the experiments must of necessity be of short duration, since a routine diet can not be adhered to for so long a time as with animals, and fluctuations in body-weight are, therefore, by no means a proper index of gain or loss of body-material.

CHANGE IN BODY-WEIGHT AS INDEX OF BODY CONDITION.

Factors involved in change of body-weight.—An increase in body-weight is a resultant of a number of factors. There may have been actual additions to protein, fat, carbohydrate, and water, these four being the principal ingredients of the body, or there may have been an increase in two or three of these compounds with an actual decrease in the others, and there may have been losses from three of them compensated by a gain in the fourth. It is evident, therefore, that a gain in body-weight is of real service only when it indicates increase of material other than water, and yet a large majority of the fluctuations in the body-weight can be attributed to material changes in the water-content of the body. When it is considered that some 60 per cent of the total weight of the body is water, and this water is easily lessened or increased, it can be seen that the gain or loss of a few pounds by the body may be very largely due to fluctuations in water-content and in no wise gives a true idea of the addition to or loss from the store of organic body-material. This fact has frequently been the source of considerable error in experiments of short duration, in that a diet manifestly inadequate for maintenance has actually been partaken of for 3 or 4 days while the body-weight of the subject of the experiment has remained practically unchanged. As a result of this apparent constancy in body-weight, a diet obviously deficient has been thought ample for the needs of the body.

INFLUENCE OF DIET ON BODY-WEIGHT AND THE STORE OF WATER.

Nearly all experimental diets differ widely from the normal. In some diets there is a large preponderance of carbohydrates, or of fat; occasionally there is a large proportion of protein. Rarely is an experimental diet so evenly adjusted as to correspond exactly to the diet on which people commonly live. A striking series of experiments has demonstrated very clearly that a change from a diet poor in carbohydrates to one rich in carbohydrates is accompanied by a considerable retention of water by the tissues of the body. Conversely, it is shown that when a change is made from the rich carbohydrate diet and a fat diet is substituted, there is a considerable loss of water to the body. It is obvious, therefore, that if a change is made from a normal diet to one containing an excessive proportion of carbohydrates, even though the total nutrients in the food may be insufficient for the maintenance of the body, the excess carbohydrates may cause the retention in the body of a sufficient amount of water to more than make up for the loss in body-material resulting from the decrease in the total food-supply. Moreover, the body must draw upon its body-material, chiefly fat, and with a diet such as is under discussion, the loss of 100 grams of fat, furnishing some 900 calories of energy, may be compensated by the addition of 100 grams of water to the body. These facts will not be seen from a mere observation of change in body-weight, and one must be very careful in drawing deductions from such changes, particularly in experiments of short duration.

EFFECT OF TRANSITION FROM LARGE CARBOHYDRATE TO LARGE FAT DIET.

The influence of marked changes in diet upon the body-weight has been shown in connection with a series of experiments conducted in the laboratory of Wesleyan University.[1] The diet of the subject in this series was for three days largely carbohydrate. It was then suddenly changed to a diet having equal energy which, however, was derived in large part from fat. The changes in body-weight during the series were most remarkable and interesting. The series consisted of work experiments, and the amount of energy in the diet was, therefore, large. During the carbohydrate period there were ingested about 970 grams of solid matter each day and sufficient water in food and drink to make the total weight of food and drink about 4500 grams per day. During 3 days on this diet, the body-weight as determined by a platform balance increased on the average 61 grams per day. The more accurate determinations of the gains and losses of body-material calculated from the amounts of protein, fat, carbohydrates, water, and ash katabolized showed an average gain of 88 grams per day.

On the fourth day of the series, the diet was so changed that the greater part of the energy came from the fat rather than the carbohydrates. The fat

[1] Benedict and Milner, U. S. Dept. Agr., Office Expt. Stas. Bul. 175, 1907.

diet contained about 750 grams of solid matter and sufficient water to make the total weight of the materials ingested equal 3860 grams on the first day and 4900 grams on each of the other 2 days, the average for the 3 days being 4550 grams per day. Although the total weight of food and drink ingested during the fat period was somewhat greater than during the carbohydrate period, there was actually a very marked loss to the body, averaging 914 grams per day, as determined by the balance with which the subject was weighed. The computations of the gains and losses of protein, fat, carbohydrate, water, and ash showed an average daily loss of 974 grams. That this loss in weight was in large part water is shown by an examination of the data, by which it is seen that during the fat period there was an average loss from the body of 12 grams of protein, 47 grams of fat, 2.5 grams of carbohydrate, 906 grams of water, and 7 grams of ash per day. Even on the third day of the period the results show a loss of some 800 grams of water.

Although there are differences between the balance as found by means of the actual weights of the subject and that calculated from the materials gained or lost, it is reasonable to suppose from a careful inspection of the analytical data, that the losses in weight as computed from the gains and losses of material are somewhat more accurate than those obtained from the weights of the man. The apparatus then in use for weighing the man, while satisfactory for long experiments, has since been much improved, as its accuracy was by no means all that could be desired in studying such a problem as this. Fortunately, we have the direct chemical data indicating the katabolism of the protein, fat, carbohydrates, water, and ash.

The total energy furnished by both diets was substantially the same and the amount of external work performed was identical in both experiments. The heat eliminated by the body was on the average 70 calories larger in the experiment with the fat diet. It is significant that during the 6 days with the two diets, the body sustained a continuous loss of energy approximating 500 calories per day, and that during the 3 days with the carbohydrate diet the subject gained on the average about 60 grams per day.

Value of further study of diet as influencing the store of water.—Further experiments are much needed to study the influence of varying diets upon the store of preformed water in the body. Such experiments would be of practical value in studying the effects of the ingestion of salt, mineral metabolism, and the gains or losses of weight noted in pathological cases. This influence of diet is of particular importance in cases of dropsy. What factor determines the retention of water and what factor determines the loss of water is certainly of great importance, and more experiments on this point should be made. It is apparent, therefore, that but little reliance can be placed upon fluctuations in body-weight in experiments of short duration, if such marked changes can occur during a period of 6 days, when muscular activity, energy of diet, and protein ingestion remain constant, and variations occur only in the relative

proportions of carbohydrates and fat. It is highly improbable that the loss of several hundred grams of water per day, shown in the period with fat diet, would continue a month or more, and, as stated previously, changes in body-weight are to be taken, therefore, as of significance only when the experiment continues for a period of several weeks. Certainly, for short experiments, body-weight is for the most part wholly without significance.

INSENSIBLE PERSPIRATION.

Studies of other investigators.—Aside from the fluctuations in body-weight which may be, as we have seen, fluctuations in large part of preformed water in the tissues of the body, there is an interesting observation in regard to changes in body-weight which the experiments here presented throw much light upon, namely, the so-called "insensible perspiration." The early observations of Sanctorius showed that the body is continually undergoing a loss, and recuperating after every meal, the loss being gradual save when urine or feces are passed. Singularly enough, these investigations of Sanctorius were not supplemented by any of scientific value until the exceedingly exact investigations of Lombard. While Sanctorius utilized his knowledge of the insensible perspiration, that is, the loss by gaseous emanations from the body, he made no careful study other than could be made with a crude form of steelyard. In recent years Lombard has attacked the problem with much success and has succeeded in constructing a most sensitive balance upon which the subject can be weighed, and variations in weight amounting to but a few milligrams are graphically recorded. His observations have thus far been confined to noting the loss in weight during short periods with normal respiration and when the subject holds his breath. Under the latter conditions the data regarding the cutaneous respiration are obtained. The possibilities of studying the gaseous emanations by this method are well set forth in his discussion of the apparatus.[1]

INSENSIBLE LOSS BY GASEOUS EXCHANGE AN AID IN OBTAINING INTERMEDIATE BODY-WEIGHTS.

In connection with the metabolism experiments made at Wesleyan University, the importance of securing accurate measures of body-weight led ultimately to a study of the insensible perspiration and, as determined from the gaseous exchange, the insensible losses are now taken into consideration in obtaining intermediate body-weights when desired. All the ingesta and egesta in these experiments are carefully measured, hence it is not difficult to correct an initial body-weight for the sudden fluctuations due to drinking of water, taking of food, passing urine, or defecation, and thus determine the body-weight at different hours of the day. Making these allowances, it is possible, therefore, to construct a curve showing the gradual loss in weight, *i. e.*, the insensible perspiration. Few people realize that there is a persistent gradual loss in

[1] Lombard, Journ. Amer. Med. Assoc., 1906, 47, pp. 1790-1793.

weight from minute to minute. During the day the frequent drinking of water, taking of food, passing of urine, and defecation, tend to obscure the fact that there is this persistent loss in weight. On the other hand, body-weights taken immediately before retiring at night and immediately on rising in the morning before urine is passed or water drunk show a loss in weight which is reasonably constant with uniform conditions.

EXPERIMENTS ON LOSS DURING THE NIGHT.

A series of experiments made by one of us shows very conclusively that the loss in body-weight during the night may be studied with considerable accuracy by means of platform scales weighing to within 10 grams. These are so-called "silk scales" and are inexpensive. The observations which were made on 2 persons, one a man and the other a woman, showed that the loss in body-weight during the night was relatively constant. The fluctuations were due in large part to changes in temperature of the season. On hot nights with a high degree of humidity, when the subjects were more or less restless, the loss in weight was very noticeable. On cold nights, when the subjects remained quietly covered with bed-clothing, the loss in weight was at a minimum. This is somewhat contrary to expectation, as we would naturally expect less vaporization of water in moist air. Apparently the restlessness more than compensated the possible decrease in vaporization.

INSENSIBLE PERSPIRATION IN CONNECTION WITH METABOLISM EXPERIMENTS.

METHOD OF OBTAINING INSENSIBLE LOSS BY CALCULATION.

In the experiments here reported, the body-weight was carefully recorded by means of a platform scale similar to the type mentioned above. This scale was arranged outside of the respiration calorimeter in accordance with the plan shown in a previous publication.[1]

The subject was weighed sitting in an arm-chair suspended from the scale, and under most advantageous conditions the body-weight could be recorded to within 2 to 4 grams. Consequently, during experiments in which the body-weight was carefully recorded at the beginning and end, and the urine, drinking water, food, and feces were carefully weighed, it is possible to compute the insensible perspiration from hour to hour. A simple illustration will serve to show this. With one subject the body-weight at the beginning of an experiment was 68,220 grams; at the end of the experiment, 7^h 15^m later, the body-weight was 68,904 grams. There was then, as recorded by the balance, an increase in weight of 684 grams, but during this period the subject ate 1049 grams of food and drank 136 grams of water and there were 188 grams of urine voided. Consequently, making allowances for the food, drink, and urine,

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[1] Atwater and Benedict, Carnegie Institution of Washington Publication No. 42, 1905, p. 159.

TABLE 46.—*Insensible perspiration during work and rest.*[1]
[Quantities per hour.]

Subject and experiment number.	Duration.	Amt. per hour.
Work experiments.	*Hours.*	*Gms.*
J. C. W.:		
	24	172
56	24	190
	24	170
	24	200
57	24	189
	24	187
B. F. D.:		
61	24	165
Mar. 1, 1904	12	251
Mar. 2, 1904	12	170
A. L. L.:		
	24	140
62	24	156
	24	159
	24	156
63	24	172
	24	163
64	24	276
92	24	153
	24	162
93	24	163
	24	166
Rest experiments.		
H. F.:		
58	24	23
B. F. D.:		
103	9	49
	24	60
60	24	33
	24	26
104	11	42
106	7	52
107	15	56
A. L. L.:		
65	24	43
66	24	37
67	24	41
	24	43
68	24	30
	24	32
	24	32
69	24	40
	24	34
	24	35
	24	36
70	24	43
	24	49
145	10	36
147	11	31
S. A. B.:		
	24	35
71	24	34
	24	25
	24	25
72	24	24
	24	26
	24	28
73	24	26
	24	25
	24	23
	24	25
74	24	24
	24	24

Subject and experiment number.	Duration.	Amt. per hour.
Rest experiments (cont.)	*Hours.*	*Gms.*
S. A. B. (cont.)		
	24	29
	24	27
	24	28
75	24	25
	24	24
	24	23
	24	23
	24	27
76	24	27
	24	29
	24	29
77	24	24
	24	27
	24	27
C. R. Y.:		
78	24	46
132	18	48
	9	49
80	24	41
	24	43
H. E. S.:		
	9	51
79	24	35
	24	30
A. H. M.:		
135	7	32
81	24	27
	24	27
139	9	26
140	9	34
141	11	40
142	11	30
H. C. K.:		
82	24	38
	24	41
153	9	37
H. R. D.:		
83	24	30
	24	28
84	24	32
148	10	28
149	9	27
150	11	38
N. M. P.:		
17	4	59
85	24	34
	24	36
86	24	45
H. L. K.:		
20	4	46
164	4	36
128	7	43
87	24	38
	24	35
88	24	33
	24	36
D. W.:		
89	24	36
	24	35
90	24	35
	24	38

Subject and experiment number.	Duration.	Amt. per hour.
Rest experiments (cont.)	*Hours.*	*Gms.*
J. A. R.:		
1	4	52
162	4	39
H. D. A.:		
2	4	58
163	4	59
H. G.:		
3	4	42
156	4	37
F. N. C.:		
4	4	47
159	4	38
J. V. C.:		
5	4	44
171	5	50
A. M.:		
6	4	79
165	4	48
F. E. R.:		
7	4	49
158	4	57
J. W. H.:		
8	4	66
175	5	55
C. A. R.:		
9	4	45
168	4	48
G. H. H.:		
10	4	41
174	4	40
H. L. W.:		
11	4	45
157	4	49
D. R. F.:		
12	4	38
166	4	42
J. N. T.:		
13	4	67
167	4	44
H. C. A.:		
14	5	48
160	4	35
F. C. B.:		
15	5	56
37	5	56
G. E. H.:		
16	4	38
173	4	36
G. W. S.:		
18	4	38
176	4	29
A. G.:		
19	4	41
169	4	53

[1] Experiments Nos. 1 to 22 are for mental work. See U. S. Dept. of Agr., Office of Exp. Stas. Bul. 208, 1909.

TABLE 46.—*Insensible perspiration during work and rest*[1]—Continued.

[Quantities per hour.]

Subject and experiment number.	Duration.	Amt. per hour.	Subject and experiment number.	Duration.	Amt. per hour.	Subject and experiment number.	Duration.	Amt. per hour.
Rest experiments (cont.)	*Hours.*	*Gms.*	*Rest experiments* (cont.)	*Hours.*	*Gms.*	*Rest experiments* (cont.)	*Hours.*	*Gms.*
J. T. H.:			B. N.:			R. A. M.:		
108*a*	4	49	116	8	49	126	7	49
G. G. R.:			117	7	45	127	8	24
21	4	59	118	8	51	H. A. P.:		
170	4	59	F. L. T.:			129	8	44
E. M. S.:			119	7	43	130	7	53
22	4	50	W. R. L.:			W. E. D.:		
172	4	45	120	7	48	131	7	57
H. L.			W. H. L.:			J. H. K.:		
Apr. 4, 1905	8	32	121	8	41	152	11	36
T. M. C.:			122	7	46	C. F. S.:		
110	5	37	F. W. H.:			177	4	51
111	7	38	123	7	42	178	4	51
H. C. M.:			J. R.:			G. E. B.:		
112	8	51	124	7	50	179	4	46
113	7	52	R. D. M.:			180	5	44
S. C. D.:			125	7	41	181	5	35
114	7	42				Average, rest experiments.	....	40
115	7	46						

[1] Experiments Nos. 1 to 22 are for mental work. See U. S. Dept. of Agr., Office of Exp. Stas. Bul. 208, 1909.

it is seen that the insensible perspiration from this subject was 1049 + 136 — 684 — 188 = 313, or an insensible loss amounting to 313 grams in $7^h\,15^m$. This is at the rate of 43 grams per hour. It frequently happened in the short experiments that the change in body-weight gave the insensible loss directly.

FLUCTUATIONS IN THE INSENSIBLE LOSS.

Obviously, muscular activity would materially alter the insensible loss since there would be a marked increase in the water given off and the carbon dioxide produced. For the purpose of securing and comparing normal data, therefore, the results have been tabulated chiefly for rest experiments. These results are shown in table 46 herewith. The very marked influence of muscular activity upon insensible loss is well shown in the few work experiments here given, which are included for that sole purpose. The remaining experiments in the table were all made with subjects at rest and the averages and deductions are drawn entirely from these.

Influence of relative humidity.—It is observed that frequently with the same subject, even excluding muscular exercise, there is considerable variation in the insensible perspiration per hour. These fluctuations are often easily explained by the relative humidity of the air. In the rest experiment, No. 60, for example, there were 3 days in which the ventilating conditions varied markedly from day to day. On the first day the subject wore a mask by means

of which the products of respiration from the lungs were withdrawn immediately and carried out of the chamber, and consequently he breathed the air of the chamber non-contaminated by carbon dioxide or water from the lungs. There was, however, the water vaporized from the skin. On this day, when the relative humidity was not far from 30 per cent, the insensible perspiration amounted to 60 grams per hour. On the second day, the subject wore no mask, but the conditions of ventilation were such as to allow the carbon dioxide to increase enormously inside the chamber. During this time there was a condensation of water on the surface of the heat-absorbers, and hence there was a larger relative humidity (about 60 per cent) during this day of the experiment. On the third day, when the ventilating conditions were substantially those ordinarily obtaining in metabolism experiments with the respiration calorimeter, the average humidity was not far from 50 per cent. The insensible perspiration for the last 2 days was 33 and 26 grams per hour, respectively, the variation for the whole experiment being from 60 to 26 grams per hour.

Variations with the same individual.—There are, however, as an inspection of the table will show, noticeable differences in different experiments with the same subject, such as can be explained only by assuming that the larger insensible loss is the result of increased total metabolism accompanying increased minor muscular activity. An examination of the data obtained with especially well-trained subjects, who endeavored to adjust the muscular activity from day to day so as to have all the experiments strictly comparable, shows that while the insensible loss may vary considerably with different individuals, with the same individual under like conditions of experimenting the loss is relatively constant. This is nowhere more strikingly shown than in the results with the subject, S. A. B., with whom experiments covering 27 days were made. The insensible loss varies from 23 to 35 grams per hour, and excluding the first 2 days of experimenting, the variation was from 23 to 29 grams per hour.

Average Insensible Loss Per Hour During Rest.

While, therefore, the insensible perspiration may with muscular work rise as high as 276 grams per hour, it is seen that in this large number of rest experiments there is a variation from 23 to 79 grams per hour. The average of 158 days, covering 2150 hours, shows that the insensible perspiration of normal healthy men, sitting, lying asleep or awake, or engaged in minor activities, is 40 grams per hour.

NATURE OF THE INSENSIBLE PERSPIRATION.

When the body is not being supplied with either drink or food, and when no urine or feces are passed, the body-weight continues to decrease by virtue of the fact that there is a constant loss of material, *i. e.*, water-vapor and organic material that is oxidized to water and carbon dioxide. In reality the insensible

perspiration is not a measure of either the carbon dioxide or the water-vapor given off from the body, but includes certain amounts of carbon and hydrogen from organic material.

The water leaving the body in the form of vapor may in large part result from the simple evaporation of water from the lungs and skin. A small quantity, however, is water resulting from the oxidation of organic hydrogen, and since in the oxidation of every gram of such hydrogen there are 8 grams of oxygen taken from the air, obviously the 9 grams of water-vapor thus formed from organic hydrogen does not represent a loss of weight to the body of more than 1 gram of hydrogen. Under conditions of rest there are from 200 to 300 grams of water resulting from the oxidation of organic substances leaving the body each day, and one-ninth of this amount, or approximately 30 grams, is the weight of the organic hydrogen which is lost from the body. It is thus seen that with an hourly insensible perspiration of about 40 grams, the decrease in body-weight in 24 hours due to the loss of organic hydrogen would be nearly equal to the insensible loss for 1 hour.

A considerable proportion (eight-elevenths) of the carbon dioxide exhaled is oxygen, which is derived from the air, and inasmuch as in ordinary rest experiments there are about 700 grams of carbon dioxide per day, it can be seen that the carbon dioxide for 24 hours represents only about 190 grams of carbon lost from the material of the body, the remainder being due to oxygen from the air. On the other hand, the total weight of water vaporized from the lungs and skin, with the single exception of the oxygen in the water formed by the oxidation of organic hydrogen, is lost from the body, and is a true insensible loss.

The insensible loss is, then, only a rough approximation of the total loss of water-vapor from the body, and if a more correct determination is desired, one must deduct in rest experiments about 190 grams of carbon and about 30 grams of organic hydrogen lost from the material of the body in the course of 24 hours.

BODY-TEMPERATURE.

It has long been known that the temperature of the human body remains relatively constant. The old "blood-heat" of the earlier investigators was supposed to be a constant, and this was, indeed, one of the earlier fixed points in thermometry. With the development of more exact thermometers it was seen that, strictly speaking, this is not true, and that the body-temperature varies considerably both with regard to the portion of the body in which the temperature is taken and with regard to the influence of factors, such as muscular exercise, and particularly with regard to disturbances of metabolism accompanied by fever.[1] It is not possible here to go into a consideration of the

[1] For a most ingenious method of studying body temperatures see Gamgee, Philosophical Transactions, 1908, **200**, p. 219.

variations in body-temperature during pathological conditions, and hence the discussion must be confined to normal individuals.

FACTORS INFLUENCING BODY-TEMPERATURE.

The body-temperature is a resultant of thermogenesis, or the development of heat inside the body, and thermolysis, the dissipation of heat from the body. Ordinarily these are so well balanced that the resultant temperature remains reasonably constant. If, for any reason, there is a decrease in the radiation or dissipation of heat, unless there is a compensating decrease in the generation of heat, the body-temperature will rise. Conversely if there is a sudden increase in the radiation of heat and no corresponding increase in the generation of heat, there will be a fall in body-temperature. It can be seen, therefore, that an elaborate study of body-temperature involves the study and, so far as possible, the control of two rather fugitive factors, namely, thermogenesis and thermolysis. Any extraneous or internal influences affecting either of these factors will cause a disturbance of body-temperature. The marvelous thing about it is that the two processes are ordinarily so delicately balanced.

TOPOGRAPHICAL VARIATIONS IN BODY-TEMPERATURE.

It is now known that heat is produced not in any one locality in the body but throughout the whole organism as the result of the oxidation of tissues by oxygen carried to the different parts of the body in the blood; thus, there is an enormous source of heat production and a large surface for heat radiation. The temperature of the body is not, however, by any means the same in all parts, for we find the highest temperature in the interior of the body, deep in the rectum, the extremities present a lower temperature, and the surface of the skin obviously a still lower temperature. Using round figures, it may be said that the internal temperature of the body is approximately 37° C. (98.6° F.), and that the temperature of the skin is on the average about 32° C. (89.6° F.), a difference of 5° C. (9° F.). Between the temperature at the warmest point inside the body and the temperature of the skin there may be a gradient, and hence the average temperature of the whole human body is a difficult thing to determine.

It has often been felt by the investigators in this laboratory that one of the most important researches as yet lacking is a topographical study of body-temperature and particularly a study of the fluctuations in different parts of the body. A number of investigators have attempted this, usually by means of clinical thermometers, and occasionally by means of thermo-electric junctions, but we know of no study where the internal temperature was examined more carefully and more continuously than in an investigation made by one of us.[1] In the experiments referred to, an electrical-resistance thermometer

[1] Benedict and Snell, Pflüger's Archiv f. d. ges. Physiol., 1901, 88, p. 492; *ibid.*, 1902, 90, p. 33.

was used and simultaneous observations were made of the temperature changes in the rectum and in the well-closed axilla. It was found from this study that there was a strong tendency for the fluctuations in temperature in the two places to be parallel. This preliminary observation, however, needs further substantiation and elaboration, and it is to be hoped that ere long a more complete topographical study of the temperature changes in the body may be made. In the absence of such an investigation it is necessary to assume that any fluctuations in rectal temperature are accompanied by similar fluctuations throughout the whole body; thus, if the temperature in the rectum falls 1° C., it is assumed that the temperature of the body falls 1° C., although it is known that there are widely varying temperatures in different parts of the body.

METHODS OF OBTAINING BODY-TEMPERATURE.

As ordinarily taken, the body-temperature is recorded by a mercurial thermometer, usually under the tongue. It can also be taken in the well-closed axilla, although it has been shown that it requires a considerable period of time to warm the axilla to constant temperature. The body-temperature can also be taken in the rectum. In the private practice of physicians it is customary to use the sublingual temperature, but for the exact physiological measurements the rectal temperatures are used whenever possible. The difficulty in using the ordinary clinical thermometer is that it records but one temperature at a time, and the best study of changes or fluctuations in temperature can not well be made when the thermometer must be continually removed and the mercury shaken down. By means of an electrical-resistance thermometer inserted deep into the rectum a large number of studies of body-temperature have been made in this laboratory. These fluctuations have been reported in great detail elsewhere.[1]

With this apparatus the body-temperature can be measured to within 0.01° C. continuously, the thermometer being inserted in the rectum and there allowed to remain, except during defecation. In some experiments this thermometer has been worn continuously for 5 or 6 days. Owing to the flexible nature of the tubing through which the connecting wires are passed, the subject rarely notices the presence of the thermometer a few moments after it has been inserted. It is assumed, therefore, that records of body-temperature made under these conditions are the nearest normal. This is especially true during sleep, since with the rigid, glass-mercurial thermometer studies during sleep are somewhat abnormal, as the subject is always more or less disturbed by inserting and removing the thermometer.

[1] Benedict and Snell, *Loc. cit.;* Benedict, Amer. Journ. Physiol., 1904, 11, p. 145.

VALUE OF BODY-TEMPERATURE MEASUREMENTS IN METABOLISM EXPERIMENTS AND DATA COLLECTED.

Body-temperature measurements have in this laboratory a great value, entirely aside from their ordinary significance as physiological data, for in determining the total energy transformations in the body in metabolism experiments it is necessary to consider the changes in temperature of the human body as a whole. This has made necessary a rather elaborate study of the body-temperature. In many of the experiments reported herewith, and in others made previously in the laboratory of Wesleyan University, more exact body-temperature measurements were obtained than are common in the ordinary metabolism experiment. As a result of these investigations, therefore, we have accumulated certain fundamental data regarding the normal body-temperature. Previous publications, discussing the researches on metabolism at Wesleyan University, have dealt more or less with this subject and reference must be made to them for details. In this discussion some of this published material will be utilized in drawing deductions, but it is unnecessary and impossible to repeat the presentation of the data in this place.

BODY-TEMPERATURE MEASUREMENTS WITH CLINICAL THERMOMETER.

In much of the earlier work published from the laboratory at Wesleyan University, the temperature observations were all sublingual and made with an ordinary clinical thermometer, carefully calibrated. With 4 subjects, all young men on a maintenance diet, 528 observations were made in different experiments with a total of 72 days. The subjects were confined in the respiration calorimeter and performed no muscular work. The average temperature from 7 a. m. to 11 p. m. was 98° F. (36.67° C.), and the average range during that time was 1.47° F. (0.82° C.). These records were all made by trained subjects who had had much experience in taking temperature observations, and they were practically all taken sublingually. A few were axillary, but these were taken only after long closure of the axilla and therefore can reasonably be compared with the buccal temperatures.

In a longer series of 84 experiments with 46 different subjects, the sublingual temperature observations were taken between 7 a. m. and 6 p. m. Usually the experiments did not last more than 5 or 6 hours, generally beginning in the morning at 8 o'clock and ending shortly after noon; occasionally an experiment began at noon and ended about 6 o'clock at night. As a result of 252 observations, it was found that the average temperature of these subjects during the day period was 98.3° F. (36.83° C.), and that the average range was 0.49° F. (0.27° C.).

With regard to these two series of observations it can be stated that the first series covered a longer period of the day and was by far the more accurate, though made with fewer subjects. The second series was made with a larger

number of subjects and therefore gives a better average, but the subjects had not acquired the same skill in taking the temperature as those who had had previous experience.

BODY-TEMPERATURE MEASUREMENTS WITH A RECTAL THERMOMETER.

Fortunately, in many of the experiments already published or presented in this report, the body-temperature was taken with sufficient accuracy and with sufficient frequency to warrant publication as furnishing evidence regarding the rectal temperature of men during the 24 hours and during certain periods of the day, since the observations were continuous. Furthermore, the errors incidental to taking the temperature in the mouth or due to the inexperience of the subjects in taking their own temperature are here avoided, and we deal exclusively with temperatures measured deep in the rectum by electrical means with an accuracy not far from 0.01° C.

In discussing these results, the experiments may be advantageously subdivided into three groups: (1) experiments of long duration in which food was taken; (2) experiments of long duration in which no food was taken; and (3) experiments of short duration, covering a part or all of the waking hours of the day. The subjects occupied the respiration chamber in all of these experiments and no muscular work was done.

TABLE 47.—*Body-temperature with rectal thermometer in experiments with food during 24 hours.*

Subject.	Date.	Minimum.		Maximum.		Range.	Average.	
		°C.	Time of day.	°C.	Time of day.		Observations averaged.[1]	°C.
	1900.							
J. C. W...	Dec. 9–10	36.38	$2^h 00^m$ a.m.	37.65	$4^h 00^m$ p.m.	1.27	25	37.14
	10–11	36.73	6 00 a.m.	37.66	5 00 p.m.	0.93	25	37.24
	1903.							
H. F.	Nov. 10–11	36.71	7 00 a.m.	37.17	10 00 p.m.	0.46	8	36.95
	11–12	36.29	7 00 a.m.	37.93	10 00 p.m.	1.64	8	37.43
	12–13	37.54	10 00 a.m.	38.23	10 00 p.m.	0.69	8	37.80
	1904.							
B. F. D...	Jan. 27–28	35.99	7 00 p.m.	36.78	10 00 a.m.	0.79	8	36.36
	28–29	36.12	1 00 a.m.	36.71	7 00 a.m.	0.59	8	36.50
	29–30	36.28	1 00 a.m.	36.92	7 00 p.m.	0.64	8	36.59
A. L. L...	Dec. 20–21	36.33	5 00 a.m.	37.01	9 00 p.m.	0.68	12	36.79
	21–22	36.38	7 00 a.m.	37.86	7 12 p.m.	1.48	12	37.09
	1906.							
	Apr. 6–7[2]	36.31	12 24 a.m.	37.04	7 00 a.m.	0.73	24	36.70
	19–20[3]	35.67	12 24 a.m.	36.97	9 20 a.m.	1.30	24	36.37
	1905.							
S. A. B...	Mar. 12–13	36.18	1 00 a.m.	37.56	3 00 p.m.	1.38	12	37.04
H. L. K...	Dec. 13–14	35.98	1 40 a.m.	37.20	1 48 p.m.	1.22	24	36.68
	14–15	36.08	3 36 a.m.	37.16	7 44 p.m.	1.08	24	36.60
	15–16	35.89	4 28 a.m.	37.00	8 00 p.m.	1.11	24	36.61
	16–17	35.98	4 24 a.m.	37.25	4 44 p.m.	1.27	24	36.75
	1906.							
H. R. D...	Apr. 10–11[2]	36.47	11 28 p.m.	37.44	7 32 a.m.	0.97	24	36.93
	May 9–10[2]	36.26	2 08 a.m.	37.12	4 40 p.m.	0.86	20	36.70
H. C. K...	May 15–16[3]	36.39	11 48 p.m.	36.83	7 08 p.m.	0.44	24	36.63
	22–23[3]	36.09	1 56 a.m.	36.71	12 36 p.m.	0.62	24	36.41
Average		....	....	....	....	0.96	....	36.82

[1] The records were in each case taken at regular intervals throughout the day.
[2] Unpublished experiment.
[3] Partially reported in this publication.

IN EXPERIMENTS WITH FOOD.

In table 47 the observations of the body-temperature with the rectal thermometer in experiments with food have been collected. The results of experiments with 8 different subjects are here given for a total of 21 days of 24 hours each. The number of observations per day is shown to have varied from 8 to 25, and in the last column of the table is recorded the average temperature. Deferring for the moment the discussion of the time of the minimum and maximum temperatures and of the range for the day, it is seen that the average temperature of these men was 36.82° C. (98.3° F.).

TABLE 48.—*Body-temperature with rectal thermometer in experiments without food during 24 hours.*

Subject.	Date.	Minimum.		Maximum.		Range.	Average.	
		°C.	Time of day.	°C.	Time of day.		Observations averaged.[1]	°C.
J. C. W...	1900. Dec. 13–14	36.35	1h 00m a.m.	37.47	9h 00m a.m.	1.12	25	37.11
	1901. Jan. 19–20	36.03	4 00 a.m.	36.54	1 00 p.m.	0.51	25	36.35
	Mar. 6–7	35.81	1 00 a.m.	36.34	7 00 p.m.	0.53	25	36.13
	Mar. 31 Apr. 1	36.35	2 00 a.m.	37.25	4 00 p.m.	0.90	25	36.76
	Apr. 1–2	36.28	3 00 a.m.	37.18	12 00 noon	0.90	25	36.73
B. F. D...	1903. Dec. 18–19	36.35	1 00 a.m.	36.94	7 00 p.m.	0.59	12	36.67
	19–20	36.40	11 00 p.m.	36.93	5 00 p.m.	0.53	12	36.70
	20–21	36.40	3 00 a.m.	37.13	3 00 p.m.	0.73	12	36.79
A. L. L...	1904. Dec. 16–17	36 30	1 00 a.m.	36.91	7 00 p.m.	0.61	12	36.60
	17–18	36.61	5 00 a.m.	37.45	7 00 p.m.	0.84	12	36.95
	18–19	36.63	11 00 p.m.	37.19	1 00 p.m.	0.56	10	36.97
	19–20	36.33	3 00 a.m.	36.87	7 00 p.m.	0.54	12	36.60
S. A. B...	1905. Jan. 7–8	35.78	11 00 p.m.	37.14	9 00 a.m.	1.36	12	36.61
	Mar. 4–5	35.95	1 12 a.m.	36.90	1 00 p.m.	0.95	11	36.50
	5–6	35.76	1 00 a.m.	36.76	7 00 a.m.	1.00	12	36.46
	6–7	35.60	1 00 a.m.	36.87	7 00 a.m.	1.27	11	36.48
	Apr. 8–9	35.53	1 00 a.m.	36.38	11 00 a.m.	0.85	11	36.12
H. E. S...	Oct. 13–14	36.55	7 00 a.m.	37.33	5 00 p.m.	0.78	12	36.99
	14–15	36.90	5 00 a.m.	37.53	9 00 p.m.	0.63	12	37.19
C. R. Y...	Oct. 27–28	36.78	1 00 p.m.	37.16	5 00 a.m.	0.38	12	36.96
	28–29	37.17	11 00 a.m.	37.74	1 00 a.m.	0.57	12	37.43
A. H. M..	Nov. 21–22	35.97	1 00 p.m.	36.80	3 00 p.m.	0.83	12	36.31
	22–23	36.53	1 00 p.m.	37.18	7 00 p.m.	0.65	12	36.77
H. C. K...	24–25	36.41	1 00 a.m.	37.30	9 00 a.m.	0.89	11	36.82
	25–26	36.65	1 00 a.m.	37.36	9 00 p.m.	0.71	12	37.00
H. R. D...	Dec. 5–6	36.20	7 00 p.m.	36.99	11 00 a.m.	0.79	12	36.52
	6–7	36.19	11 00 p.m. 3 00 a.m.	36.93	5 00 p.m.	0.74	12	36.60
N. M. P...	9–10	36.13	3 00 a.m.	36.93	5 00 p.m.	0.80	12	36.53
	10–11	36.61	11 12 a.m.	37.32	9 00 p.m.	0.71	11	36.96
D. W.	1906. Jan. 10–11	35.77	3 00 a.m.	36.45	7 00 p.m.	0.68	11	36.13
	11–12	35.62	5 28 a.m.	36.45	3 00 p.m.	0.83	12	36.09
Average		....	....	....	....	0.77	....	36.67

[1] The records were in each case taken at regular intervals throughout the day.

IN EXPERIMENTS WITHOUT FOOD.

Body-temperature in experiments without food has been given previous treatment,[1] but the results are here collected for comparison. The data for 11 sub-

[1] Benedict, Carnegie Institution of Washington Publication No. 77, 1907; Atwater and Benedict, U. S. Dept. Agr., Office Expt. Stas. Bul. 136, 1903.

jects are given in table 48 and cover 31 days of 24 hours each. The average temperature for all the subjects was 36.67° C. (98° F.). As has been pointed out in a previous discussion, the absence of food does not tend to materially lower the body-temperature, and a comparison of the results in the two tables shows that subsequent data likewise emphasize this point.

DURING WAKING HOURS IN SHORT EXPERIMENTS.

Records of body-temperature with the rectal thermometer during the waking hours in short experiments are shown in table 49. The subjects were, with one exception, young men who had eaten ordinary amounts of food or who had been without food for some hours and did not work. These results are of unusual interest as indicating the average temperature of the human body during the hours of the day when the subjects might normally visit a physician's office. Some 15 experiments were made with 7 subjects, and they usually extended from 8 in the morning until late in the afternoon. The number of observations in each experiment varied from 4 to 11, and the average body-temperature for all the subjects was 36.74° C., or 98.1° F.

TABLE 49.—*Body-temperature with rectal thermometer during waking hours in short experiments.*

Subject.	Date.	Period of observation.	Range.	Average.	
				Observations averaged.[1]	°C.
A. H. M.	1905. Nov. 14	$9^h 10^m$ a.m. to $12^h 15^m$ p.m.	0.33	4	37.10
A. H. M.	1906. Feb. 14	8 20 a.m. 5 00 p.m.	.57	9	36.30
A. H. M.	Mar. 26	8 00 a.m. 4 35 p.m.	.21	9	36.81
A. H. M.	Apr. 2	8 12 a.m. 4 57 p.m.	.61	9	36.53
A. H. M.	Apr. 5	8 06 a.m. 4 30 p.m.	.54	9	36.34
H. A.	1905. Nov. 15	7 00 a.m. 11 00 a.m.	.51	5	37.15
D. W.	1906. Jan. 14	7 00 a.m. 1 00 p.m.	.27	7	37.17
C. R. Y.	Feb. 8	8 42 a.m. 12 15 p.m.	.47	4	36.66
A. L. L.	Feb. 9	8 00 a.m. 5 00 p.m.	.63	10	36.78
A. L. L.	Mar. 20	8 10 a.m. 5 10 p.m.	.52	10	36.78
A. L. L.	Apr. 3	8 00 a.m. 4 40 p.m.	.44	9	36.65
H. R. D.	Feb. 10	8 24 a.m. 5 16 p.m.	.46	9	36.73
H. R. D.	Mar. 24	8 00 a.m. 4 40 p.m.	.32	9	36.80
H. R. D.	Mar. 31	8 12 a.m. 6 45 p.m.	.45	11	36.79
J. H. K.	Apr. 17	7 16 p.m. 11 16 p.m.	.31	5	36.53
Average			.44	....	36.74

[1] The records were in each case taken at regular intervals throughout the day.

NORMAL BODY-TEMPERATURE.

The idea of constancy in body-temperature has become so generally accepted that it is commonly believed that the body remains at the temperature of 98.6° F., or 37° C., without material change other than that produced by disease. This impression is so firmly fixed that one finds to-day on all clinical thermometers a special mark opposite this temperature to indicate what is

supposed to be the normal temperature. It is somewhat difficult to place the exact history of the selection of this mark and it may be looked upon as more or less of a thermometric fetich which has been worshiped by long-continued usage.

An examination of the results presented in the three foregoing tables leaves no doubt as to three points: (1) that the body-temperature of a given individual may fluctuate through a considerable range during the 24 hours, and from day to day; (2) that the same individual may have an average body-temperature which varies widely on different days; and (3) that two individuals may differ considerably in regard to their average body-temperature.

DAILY RANGE AND FLUCTUATION IN RANGE FROM DAY TO DAY.

Taking these points into consideration it is obviously erroneous to assume that there is a normal body-temperature to which all body-temperature measurements can be referred. Particularly is this the case when it is considered that it is common, at least among laymen, to suppose that a temperature above 98.6° F. indicates a febrile condition. It is a well-known fact, however, and familiar to all clinicians, that many persons, otherwise in perfectly normal health, may show temperatures considerably higher than any of those recorded here in these observations and still give no indications of a pathological lesion. It will be profitable to examine more in detail the fluctuations in individual temperatures, and the differences between individuals as shown in the data presented.

For an adequate treatment of this subject, more elaborate observations should be recorded than were deemed practicable in this discussion. With the electrical-resistance thermometer employed in these experiments, observations were taken every 4 minutes, and consequently more or less continuous curves can be drawn indicating the true temperature fluctuations. Curves of this nature have been prepared in an elaborate discussion in an earlier publication.[1] In tables 47 and 48 are recorded only the minimum and maximum temperatures, and the time of day at which each was observed.

With regard to the range of temperature that can be experienced on any given day the data shown in table 47 for experiments with food may first be examined. If we consider the 2 days with the first subject, J. C. W., we find that the range in temperature varied from 1.27° C. (2.29° F.) on the first day to 0.93° C. (1.67° F.) on the second day. Similar variations in fluctuations from day to day may be observed with other subjects. With H. F., for example, on November 10-11, the range was 0.46° C. (0.83° F.), and on the next day, 1.64° C. (2.95° F.). On the other hand, with one subject, H. L. K., the range was practically identical for 4 consecutive days, varying only from 1.08° C. (1.94° F.) to 1.27° C. (2.29° F.). On the whole, however, it is clear

[1] Benedict and Snell, *loc. cit.*

that there may be a very considerable range in the temperature for 24 hours which averages in experiments with food 0.96° C. (1.73° F.). It is of interest to note, also, the minimum and maximum temperatures during the day, particularly the hours at which they occur. In general, the minimum temperature is observed during the early morning hours, while usually the maximum temperature is found in the late afternoon or early evening. There are some few sharp exceptions to this, as, for example, with the subject B. F. D., January 28-29, 1904, the maximum temperature occurred at 7 a. m. Referring to the previously published discussion of body-temperature,[1] it can be seen that these experiments substantiate in a general way the deductions there made, that the minimum temperature occurs some time in the early morning hours and the maximum during the late afternoon hours.

The experiments without food given in table 48 likewise show a considerable change in temperature during the day and, indeed, on different days with the same subject. The average range of temperature throughout the day is somewhat less, however, than it is in experiments with food, averaging 0.77° C. (1.39° F.) as against 0.96° C. (1.73° F.) with food. One of the most marked influences of the absence of food on body-temperature is noted in the time at which the minimum and maximum temperatures occur. While the minimum temperature still appears during the late night or early morning hours, the maximum temperature, instead of appearing uniformly in the late afternoon, is frequently found in the forenoon or early morning. These two series of experiments (experiments with food, and without food) were not, however, made with the primary object of studying body-temperature, and hence an adequate study of the effects of the ingestion of food on body-temperature, somewhat differently designed, should be made. Researches that will supplement and amplify the most interesting observations of Rancken[2] regarding the influence of the ingestion of food upon body-temperature are greatly needed.

Of perhaps more general interest, inasmuch as the conditions approximate more closely those obtaining in the visit of a patient to a doctor's office, are the results given in table 49. Here the range is found to be much less than that in the experiments in tables 47 and 48, amounting on the average to 0.44° C. (0.79° F.). It is to be observed, however, that in the range as here measured, the minimum, which naturally falls in the early morning hours, is not included, although in many experiments the afternoon maximum may appear. The range in temperature during the day, however, may vary considerably with the same individual, as is shown in the case of A. H. M., with whom the range varied from 0.21° C. (0.38° F.) to 0.61° C. (1.10° F.). On the other hand, the variations shown by A. L. L. and H. R. D. are by no means as great. It is evident, therefore, from the data in these tables that with most individuals there is a wide range in body-temperature during the day.

[1] Benedict and Snell, *loc. cit.;* Benedict, *loc. cit.*
[2] Rancken, Skand. Archiv f. Physiologie, 1908, **21**, p. 161.

VARIATIONS IN AVERAGE BODY-TEMPERATURE FROM DAY TO DAY.

While, as is seen from the foregoing discussion, there are considerable fluctuations in the body-temperature during 24 hours, it still remains to be shown whether the average daily temperature is or is not relatively constant. The material collected in tables 47 and 48 throws considerable light upon this subject, and a close examination of the data shows that, with the same individual, even on succeeding days, there may be marked differences in the temperature average. Thus, in table 47, with the same subject, H. F., the average temperature on 3 successive days with food ranged from 36.95° C. (98.5° F.) to 37.80° C. (100° F.). With other subjects the variations from day to day are, it is true, much less, amounting to about 0.3° C. (0.5° F.). In table 48, experiments without food, there are certain noticeable variations, particularly in the widely-separated days with J. C. W., in whose case the temperature varied from 36.13° C. (97° F.) to 37.11° C. (98.8° F.), or practically 1° C. (1.8° F.).

Among the shorter experiments shown in table 49, noticeable variations appear in the results with A. H. M. The average temperature of this subject for the day, which was not, however, a 24-hour day, ranged from 36.30° C. (97.3° F.) to 37.10° C. (98.8° F.). With the two other subjects, A. L. L. and H. R. D., who were in more than one experiment, the temperatures were remarkably constant.

It is obvious, therefore, that the data in these tables tend to show conclusively that the average temperature of any individual may vary considerably from day to day. Accordingly, if such variations are found with the same individual it is not surprising to find that the average body-temperature, as well as the range, during 24 hours is markedly different for different individuals. This is strikingly shown in all the tables here presented.

The value of the average temperature for 24 hours depends, in part at least, upon the number of observations taken, and when these observations were made, since the higher temperatures are commonly experienced during the daytime. As regards the results computed from the rectal records, there would of course be a tendency for the averages to be too high in the shorter experiments, since the observations in those experiments were made usually between 9 in the morning and 5 in the afternoon. As regards the clinical averages, it has already been indicated that the larger portion of the clinical temperatures were taken during waking hours and few, if any, were obtained during sleep. This fact would tend to affect in a measure the averages given as obtained from clinical observations, and these averages are undoubtedly somewhat higher than they would be if night observations were included.

DEFINITION OF NORMAL BODY-TEMPERATURE.

From the foregoing results, it is obvious that no one point can be taken upon the thermometer as indicating the average body-temperature. Certainly the point at present in common use is too high, for the body-temperatures throughout the day rarely average as high as 98.6° F. Furthermore, for purposes of comparison it should be borne in mind that the results recorded in these three tables indicate rectal temperatures, and there is conclusive evidence to show that the temperature in the rectum may be a degree (Fahrenheit) or more higher than that in the mouth. Since, therefore, most temperatures taken by physicians are sublingual, it is obvious that the temperature of 98.6° F., as commonly given on clinical thermometers, represents far too high a value for the average normal body-temperature throughout the day. The body-temperature, furthermore, undergoes a regular rhythm during the day, the minimum from 3 to 5 a. m., a marked morning rise at about 7, a slow, steady rise during the daytime, reaching the highest point in the afternoon between 3 and 6. There is then an evening fall, accompanied by a marked falling temperature after going to bed, the minimum being reached again between 3 and 5 a. m. A number of curves showing the normal fluctuations of the body-temperature have been presented in a discussion elsewhere.[1]

With normal fluctuations in the daily temperature of every individual, and with variations among different individuals, a point emphasized in a preceding portion of this report is again brought to notice, namely, the importance of knowing the normal physiological factors of each individual. If the body-temperature of an individual is normally somewhat higher or lower than 98.6° F., it would be an observation of prime importance to the physician in treating cases of illness in which temperatures ordinarily considered abnormal were observed. While, therefore, temperatures several degrees above or below 98.6° F. may fairly be taken as indicating a probable pathological condition, it must not be forgotten that minor fluctuations above or below this point—fluctuations amounting to as much as 2° F.—may well be within the range of physiological limits and in no wise indicative of pathological conditions.

PULSE-RATE.

The pulse-rate is one of the most frequent observations made by the physician, and yet as a rule observations of pulse-rate by physicians are made under such circumstances as to exclude the records from contributions to our knowledge of the normal pulse-rate. The psychical excitement incident to the physician's visit, the possible slight apprehension on the part of the subject as to his condition, and the degree of attention frequently manifested by patients when the pulse-rate is being taken, all tend towards a pulse-rate considerably higher than would be obtained if the subject were lying quietly without any extraneous influences.

[1] Benedict and Snell, *loc. cit.*

FACTORS INFLUENCING PULSE-RATE.

The pulse-rate is influenced by many factors, chiefly muscular activity and the ingestion of food, and yet even with subjects who remain quietly sitting and without food there may be considerable variations from day to day and from hour to hour. Even the slight muscular activity incidental to sitting up and to the quiet life in a respiration chamber may produce noticeable variations in pulse-rate from day to day. In a fasting experiment previously reported,[1] the pulse-rate on the first day varied from 68 per minute at $7^h\ 30^m$ a. m. to 51 at 10 p. m. These observations were taken by the subject himself, who had had considerable experience in counting his own pulse. The general tendency of the average pulse-rate during the 7-day fast was to fall noticeably, and on the last day it was 57 at $7^h\ 30^m$ a. m. and 44 at $8^h\ 05^m$ p. m. It is thus seen that eliminating the two most potent factors influencing the pulse-rate, namely, the ingestion of food and muscular exercise, there is still opportunity for considerable variation.

METHODS OF COUNTING PULSE-RATE.

In connection with the experiments here reported, a large number of observations of the pulse-rate were taken. In many instances they were recorded by the subjects themselves, who were inside the respiration chamber, quietly seated. These subjects were requested to count their radial pulse for 2 minutes at frequent intervals during the day. At times an ordinary watch was used and at other times they were given a stop-watch and a regular number of beats, 60, was counted and the time required was noted.

Believing there was some tendency to quicken or retard the pulse-rate by having the subject take it himself, arrangements were made to record more or less automatically the pulse-rate of the subjects by means of a pneumograph so placed over the apex of the heart that the pulse-beat could be counted. The apparatus and method of using it have been described in some detail elsewhere.[2] With this apparatus, the pulse-rate could be counted by an observer outside the chamber, whether the subjects were asleep or awake, and the air transmission was so adjusted that a graphic record could be made if desired. The larger amplitude of the pointer resting on the tambour indicated the respirations, while the minor superimposed fluctuations indicated the pulse-rhythm. Subsequently, it has been found desirable to utilize a stethoscope attached to the body directly over the apex-beat of the heart, and this gives results even more satisfactory than the pneumograph, for it frequently happened that the pneumograph became slightly displaced or the pulse-beat was so feeble as to render accurate counting impossible.

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[1] Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 169.
[2] Benedict, *loc. cit.*, p. 10.

PULSE-RATE IN EXPERIMENTS.

A long series of experiments made with the respiration chamber at Wesleyan University has furnished data regarding the pulse-rate which have been so obtained that they throw definite light upon the normal pulse-rate of individuals. The experiments here discussed are only the so-called rest experiments, *i. e.*, experiments in which no external muscular work was performed, and were both with and without food. The narrow confines of the chamber, and the regularity of the routine from day to day, insure a very even muscular activity. This may be considerable so far as minor muscular movements are concerned, and may vary with different subjects, but under no circumstances was there direct muscular effort exercised other than that required to dress and undress and arrange the bed and bedding night and morning.

In a number of instances where the subjects were to be used for only one experiment and it seemed undesirable to complicate the details of the experiment by the addition of the pneumograph, we have relied upon the observations made by the subject himself.

IN EXPERIMENTS WITHOUT FOOD.

In a previous publication[1] the influence of inanition on the pulse-rate was discussed in some detail. In addition to the results considered in that discussion, there were other pulse data obtained in earlier published experiments or accumulated in later unpublished experiments. These data have been summarized and are combined with those previously discussed in table 50. The table shows the minimum and maximum pulse-rate, the average daily range, and the average daily pulse-rate for each experiment and for each individual. To give some idea of the value of the different experiments, the number of observations is likewise recorded in the table. The individual averages have been obtained in every instance by giving due value to the average in each experiment, in that the average pulse-rate for each experiment has been multiplied by the number of days, before being included in the grand average. All measurements subsequent to June 24, 1905, were secured from the pneumograph.

Table 50 is of particular value for indicating the average daily rate and the fluctuations in the pulse-rate of the same individual under like conditions of muscular activity. With the same individual, J. C. W., for example, we find in 4 experiments a daily average ranging from 48 to 69, while the grand average of all experiments without food with this subject shows that his normal pulse is 60 per minute. All the observations were made by the subject himself.

Even in experiments where the pneumograph was used such variations occur in the daily average, for with H. C. K. on November 24-26, 142 observations give the average pulse as 65, while 5 months later 35 observations in an 8-hour experiment show the average as 50. This is all the more surprising when it

[1] Benedict, *loc. cit.*, p. 318.

is considered that the earlier experiment included the night periods of sleep while the experiment in May was made during the 8 hours of the day when the subject was awake. These experiments show strikingly the possible variations in the pulse-rate of the same individual under conditions of body rest. With A. L. L. much more uniformity is found.

TABLE 50.—*Pulse-rate in experiments without food.*[1]

Subject and date.	Duration.	Minimum.	Maximum.	Average daily range.	No. of observations.	Average pulse-rate.
J. C. W.:						
Dec. 13-14, 1900...	1 day.	52	73	21	33	61
Jan. 19-20, 1901...	1 day.	44	53	9	4	48
Mar. 6- 7, 1901...	1 day.	46	75	29	15	53
Mar. 31-Apr. 2, 1902	2 days.	63	77	10	8	69
Average		54	71	16	..	60
B. F. D.:						
Dec. 18-21, 1903...	3 days.	46	68	16	69	59
May 5- 6, 1905...	1 day.	51	71	20	11	60
Average		47	69	17	..	59
H. C. K.:						
Nov. 24-26, 1905...	2 days.	49	88	30	142	65
May 13, 1906......	8 hrs.	45	64	19	35	50
Average		48	85	28	..	63
A. L. L.:						
Dec. 16-20, 1904...	4 days.	48	62	7	8	57
Feb. 7, 1906......	8 hrs.	48	66	18	23	55
Feb. 9, 1906......	8 hrs.	47	61	14	18	55
Feb. 20, 1906......	8 hrs.	52	64	12	26	57
Mar. 20, 1906......	8 hrs.	52	63	11	57	57
Apr. 3, 1906[2].....	8 hrs.	45	69	24	51	58
Apr. 20, 1907......	8 hrs.	59	68	9	18	64
May 4, 1907[3].....	8 hrs.	[4]50	62	12	32	56
Average		49	63	10	..	57
S. A. B.:						
Jan. 7-11, 1905...	4 days.	58	82	7	24	70
Jan. 28-Feb. 2, 1905	5 days.	45	68	17	45	54
Mar. 4-11, 1905...	7 days.	44	82	18	63	56
Apr. 8-12, 1905...	4 days.	52	88	24	28	69
Average		49	80	17	..	61
N. M. P.:						
Dec. 9-11, 1905...	2 days.	46	94	34	87	65
A. H. M.:						
Nov. 21-23, 1905...	2 days.	38	64	23	114	47
Feb. 12, 1906......	8 hrs.	38	51	13	12	47
Feb. 14, 1906......	8 hrs.	36	42	6	11	40
Mar. 26, 1906......	8 hrs.	50	64	14	57	58
N. M. P.—cont'd:						
Nov. 22, 1906......	14 hrs.	50	70	20	25	58
Dec. 3- 5, 1906...	2 days.	48	75	22	52	58
Mar. 6, 1907......	8 hrs.	50	63	13	13	54
Mar. 9, 1907[3].....	8 hrs.	[4]46	57	11	21	50
Mar. 16, 1907......	8 hrs.	45	59	14	15	50
Apr. 19, 1907......	8 hrs.	54	77	23	20	63
Average		45	66	19	..	53
H. R. D.:						
Dec. 5- 7, 1905...	2 days.	54	99	42	118	75
Feb. 6, 1906......	8 hrs.	57	70	13	25	63
Feb. 10, 1906......	8 hrs.	57	70	13	24	61
Mar. 24, 1906......	8 hrs.	55	76	21	68	62
Apr. 4, 1906......	8 hrs.	58	77	19	35	69
Average		55	89	32	..	71
E. H. B.:						
Mar. 7, 1907......	8 hrs.	51	68	17	21	58
Mar. 13, 1907......	8 hrs.	47	58	11	14	53
Apr. 15, 1907......	8 hrs.	50	56	6	20	53
Average		49	61	11	..	55
A. W. W.:						
Mar. 15, 1907......	8 hrs.	56	72	16	14	60
Mar. 21, 1907......	8 hrs.	57	66	9	16	60
Mar. 27, 1907......	8 hrs.	51	63	12	18	57
Apr. 12, 1907......	8 hrs.	56	71	15	23	62
Average		55	68	13	..	60
W. E. T.:						
Mar. 20, 1907......	8 hrs.	71	83	12	12	76
Mar. 26, 1907......	8 hrs.	66	78	12	18	71
May 3, 1907......	8 hrs.	69	78	9	33	73
Average		69	80	11	..	73
H. B. W.:						
Mar. 22, 1907......	8 hrs.	62	74	12	15	69
Apr. 4, 1907......	8 hrs.	61	67	6	21	63
Apr. 26, 1907[3].....	8 hrs.	[4]50	68	18	25	62
Average		58	70	12	..	65

[1] All records subsequent to June 24, 1905, were taken with pneumograph and not by the subject.
[2] Last two hours standing excluded.
[3] By subject and with pneumograph.
[4] By subject.

The differences in the pulse-rate of the subject S. A. B. have been pointed out to a considerable extent in a previous publication.[1] In these experiments, particularly that of March 4 to 11, it was found that there was a tendency for

[1] Benedict, *loc. cit.*, p. 318.

the pulse-rate to decrease during the progress of the fast. Taking this fact into consideration, the daily averages still show marked variations. With the subject A. H. M. there was likewise a marked difference in the average pulse-rate which ranges from 40 to 63. Yet to all external appearances the man was living under the same conditions of bodily activity and without food. The observations with this subject for the most part were taken by means of the pneumograph. With the remaining subjects in this table, the average pulse-rate for each individual is much alike in the different experiments, indicating a uniformity that is not observed with the subjects of a greater number of the experiments in the first part of the table. In the later experiments the exclusive use of the pneumograph may increase the accuracy of the pulse-records.

IN EXPERIMENTS WITH FOOD.

The larger number of experiments were with food, and the results for the different individuals experimented with are given in table 51. All of the results with E. O. were obtained by the subject's own observation, and the uniformity in the averages for the different experiments is very striking. Perhaps the most careful count of pulse, when made by the subject himself, was in the experiments with J. F. S. Here, in different experiments, there were variations from 73 to 84, and yet the subject was living during this time under identical conditions regarding muscular activity, and the diet was essentially the same in amount, although varying somewhat in the proportion of carbohydrates to fat. The amount of protein in the diet remained essentially constant in all experiments.

One of the most striking illustrations of the variations in the pulse-rate with the same individual is in the experiments with H. L. K. On February 20, 1905, during an experiment when he was taking an examination inside the respiration chamber, the average pulse-rate was 96. During the control experiment on March 1, 1905, it dropped to 78, and in 3 subsequent experiments it varied from 74 to 81; the grand average for this man is taken as 75. The subject A. H. M. was used in a large number of experiments, and fortunately in most of these the determination of the pulse-rate was made by means of the pneumograph. In the first experiment the pulse was extraordinarily low, *i. e.*, 45 per minute. In subsequent experiments the average was as high as 73. The grand average for this man was taken as 60. With H. R. D. there is likewise a variation in the pulse-rate, ranging from 59 to 85. The average for this subject was 70.

TABLE 51.—*Pulse-rate in experiments with food.*[1]

Subject and date.	Duration.	Minimum.	Maximum.	Average daily range.	No. of observations.	Average pulse-rate.
E. O.:						
May 5- 8, 1897...	3 days.	54	82	23	21	69
June 8-12, 1897...	4 days.	56	85	21	36	68
Nov. 8-12, 1897...	4 days.	62	73	3	8	67
Jan. 10-14, 1898...	4 days.	58	73	11	12	67
Feb. 15-19, 1898...	4 days.	56	85	14	20	68
Nov. 8-12, 1898...	4 days.	56	69	11	20	63
Dec. 20-24, 1898...	4 days.	57	67	5	16	62
Jan. 16-18, 1899...	2 days.	59	68	6	6	64
Jan. 18-20, 1899...	2 days.	58	69	9	8	64
Jan. 20-22, 1899...	2 days.	55	71	13	8	64
Mar. 13-16, 1899...	3 days.	59	72	11	9	65
Mar. 16-19, 1899...	3 days.	56	76	14	9	65
Mar. 19-22, 1899...	3 days.	56	73	13	9	65
Average		57	75	12	..	66
A. W. S.:						
Feb. 6- 8, 1899...	2 days.	66	78	4	4	71
Feb. 8-10, 1899...	2 days.	67	85	11	4	74
Feb. 10-12, 1899...	2 days.	62	81	4	4	72
Feb. 12-15, 1899...	3 days.	61	74	7	6	68
Average		64	79	7	..	71
J. F. S.:						
Jan. 23-26, 1900...	3 days.	63	89	20	63	74
Feb. 14-17, 1900...	3 days.	61	82	16	51	73
Feb. 17-20, 1900...	3 days.	72	98	25	60	84
Feb. 20-23, 1900...	3 days.	66	101	31	57	80
Average		66	93	23	..	78
J. C. W.:						
Dec. 9-13, 1900...	4 days.	57	86	29	113	68
B. F. D.:						
Jan. 27-30, 1903...	3 days.	45	58	9	15	52
June 2, 1905......	6 hrs.	45	65	20	5	56
June 3- 4, 1905...	13 hrs.	52	62	10	5	57
Average		46	59	10	..	53
H. C. K.:						
May 7, 1906......	8 hrs.	45	55	10	29	50
May 15-16, 1906[2]..	28 hrs.	44	59	15	90	50
May 22-23, 1906[2]..	28 hrs.	38	62	24	76	49
Average		42	60	18	..	50
A. L. L.:						
Dec. 20-23, 1904[3]..	1 day.	86	88	2	2	87
Feb. 13, 1906......	8 hrs.	63	87	24	19	74
Feb. 15, 1906......	8 hrs.	59	90	31	17	69
Mar. 22, 1906......	8 hrs.	56	67	11	68	60
Mar. 27, 1906......	8 hrs.	51	71	20	68	60
Mar. 30, 1906......	8 hrs.	54	85	31	51	65
Apr. 6- 7, 1906[4]..	24 hrs.	39	93	54	81	54
Apr. 19-20, 1906...	27 hrs.	42	85	43	83	58
May 13, 1907[5].....	8 hrs.	59	[6]74	15	31	64
May 27, 1907[5].....	8 hrs.	[6]52	74	22	23	61
Average		54	84	30	..	64
S. A. B.:						
Jan. 11-12, 1905...	1 day.	60	71	11	6	66
Feb. 2- 5, 1905...	3 days.	51	75	16	27	61
Mar. 11-14, 1905...	3 days.	64	91	19	27	75
Average		58	81	17	..	68
N. M. P.:						
Feb. 17, 1905......	3 hrs.	58	68	10	3	63
Feb. 27, 1905......	3 hrs.	59	73	14	4	65
Dec. 11-12, 1905...	1 day.	46	103	57	44	81
Average		49	97	48	..	78
H. L. K.:						
Feb. 20, 1905......	3 hrs.	88	105	17	9	96
Mar. 1, 1905......	3 hrs.	70	91	21	8	78
June 10, 1905......	6 hrs.	66	100	34	10	81
Dec. 13-15, 1905...	2 days.	39	111	60	68	74
Dec. 15-17, 1905...	2 days.	50	104	48	58	74
Average		48	107	51	..	75
A. H. M.:						
Nov. 13-14, 1905...	19 hrs.	39	65	25	20	45
Jan. 29, 1906......	7 hrs.	57	68	11	3	62
Jan. 30, 1906......	8½ hrs.	54	68	14	7	60
Jan. 31, 1906......	6 hrs.	49	61	12	10	56
Feb. 2- 3, 1906...	24 hrs.	41	66	25	25	50
Feb. 16, 1906......	8 hrs.	51	76	25	25	64
Feb. 19, 1906......	8 hrs.	58	88	30	23	68
Mar. 23, 1906......	8 hrs.	44	62	18	60	53
Apr. 2, 1906[7].....	8 hrs.	52	81	29	44	65
Apr. 5, 1906......	8 hrs.	51	74	23	35	61
Dec. 5- 6, 1906...	24 hrs.	50	86	36	52	70
Mar. 25, 1907......	8 hrs.	61	87	26	17	73
Mar. 28, 1907......	8 hrs.	57	72	15	15	63
Apr. 1, 1907......	8 hrs.	48	64	16	15	55
Apr. 5, 1907......	8 hrs.	62	68	6	18	64
Apr. 10, 1907......	8 hrs.	53	71	18	22	63
Apr. 29, 1907[5].....	8 hrs.	49	71	22	30	58
May 10, 1907......	8 hrs.	52	73	21	23	59
May 15, 1907[5].....	8 hrs.	60	85	25	25	68
May 24, 1907[5].....	8 hrs.	[6]55	71	16	22	63
Average		50	73	23	..	60
H. R. D.:						
Dec. 7- 8, 1905...	24 hrs.	66	112	46	63	85
Feb. 17, 1906......	8 hrs.	59	87	28	25	75
Feb. 21, 1906......	8 hrs.	61	82	21	17	72
Mar. 21, 1906......	8 hrs.	56	73	17	58	63
Mar. 28, 1906......	8 hrs.	56	82	26	46	68
Mar. 31, 1906[7].....	8 hrs.	68	86	18	60	78
Apr. 10-11, 1906[4]..	29¼ hrs.	57	92	35	81	71
Apr. 20-21, 1906[4]..	28½ hrs.	49	95	46	75	68
May 2, 1906......	8 hrs.	56	75	19	40	67
May 4, 1906......	8 hrs.	56	77	21	34	65
May 9-10, 1906[2]..	22 hrs.	49	77	28	68	59
May 17-18, 1906[2]..	28 hrs.	49	79	30	75	65
Average		55	88	32	..	70
E. H. B.:						
Mar. 19, 1907......	6 hrs.	64	91	27	13	79
Apr. 8, 1907......	8 hrs.	44	65	21	16	51
May 14, 1907[5].....	8 hrs.	[6]53	[6]78	25	30	60
Average		53	77	24	..	62
B. N.:						
Apr. 29, 1905......	6 hrs.	63	75	12	7	68
June 5, 1905......	6 hrs.	58	71	13	7	61
June 15, 1905......	6 hrs.	59	70	11	6	65
Average		60	72	12	..	65

[1] All records subsequent to June 24, 1905, are taken with pneumograph and not by the subject.
[2] Food and fasting.
[3] Pulse taken only on second day.
[4] Fasting followed by food.
[5] By subject and with pneumograph.
[6] By subject.
[7] Last two hours standing excluded.

TABLE 51.—*Pulse-rate in experiments with food*[1]—Continued.

Subject and date.	Duration.	Minimum.	Maximum.	Average daily range.	No. of observations.	Average pulse-rate.
G. E. B.:						
June 22, 1905......	3 hrs.	74	82	8	5	77
June 23, 1905......	4 hrs.	75	83	8	8	77
June 24, 1905......	4 hrs.	69	75	6	6	72
Average		73	80	7	..	75
A. W. W.:						
Apr. 2, 1907......	2 hrs.	60	69	9	6	64
Apr. 6, 1907......	8 hrs.	62	70	8	17	66
Apr. 25, 1907......	8 hrs.	60	72	12	20	65
May 2, 1907[2].....	8 hrs.	[3]49	73	24	29	58
May 9, 1907[2].....	8 hrs.	[3]51	74	23	27	62
May 25, 1907[2].....	8 hrs.	[3]51	70	19	31	61
May 28, 1907[2].....	8 hrs.	[3]52	66	14	26	57
Average		54	71	16	..	62
W. E. T.:						
Mar. 30, 1907......	8 hrs.	58	72	14	19	67
Apr. 3, 1907......	8 hrs.	59	71	12	18	65
Apr. 11, 1907......	8 hrs.	59	78	19	20	70
Apr. 16, 1907......	8 hrs.	67	81	14	20	72
Apr. 27, 1907[2].....	8 hrs.	66	77	11	27	70
Average		62	76	14	..	69
H. B. W.:						
Apr. 9, 1907......	8 hrs.	49	72	23	20	59

[1] All records subsequent to June 24, 1905, were taken with pneumograph and not by the subject.
[2] By subject and with pneumograph.
[3] By subject.

It can be proved, therefore, from these observations in experiments with food, that the average pulse-rate may vary on two successive days, even with like conditions of muscular activity and food. It is impossible here to enter more into detail with regard to the kinds of diet given and attempt to explain the variations in the pulse-rate by the differences in the kind of diet, for, as is seen in the experiments without food, there exists a large variation in the pulse-rate from day to day which obviously cannot be explained by any presumable variations in the store of protein, fat, or carbohydrates in the body. It is necessary to consider, therefore, that there is no normal pulse-rate which can be accurately referred to in all cases even with the same individual.

COMPARISON OF PULSE-RATE IN EXPERIMENTS WITH FOOD AND WITHOUT FOOD.

While it is not the purpose of this article to discuss the influence of the ingestion of food upon the pulse-rate, it is advisable in this connection to consider for a moment the average pulse-rate in experiments with and without food, and on the same subject. Consequently the data have been brought together in table 52. With certain of the subjects no comparison experiments were made, but on 12 subjects we have experiments with and without food. Contrary to the experience found in the report on inanition, mentioned previously, we find here that there is no definite rule for the pulse-rate in experiments with food as compared with experiments without food. In certain cases it is higher with food, and in other cases it is higher without food. On the other hand, the range throughout the day is almost always considerably greater in experiments with food than without, although there are one or two notable exceptions to this, particularly in the experiments with H. C. K. and B. F. D.

Summing up all of the results, we find that with 18 subjects with food the average pulse-rate was 66, and with 12 subjects without food the average was 62. Comparing the subjects with whom experiments were made both with and without food, we find that with the 12 subjects the average pulse-rate was approximately 62 per minute without food, while with food the average pulse-rate per minute was 64, an inconsiderable increase.

TABLE 52.—*Average pulse-rate in experiments with different subjects with and without food.*

Subject.	With food.		Without food.		Subject.	With food.		Without food.	
	Average daily range.	Average pulse-rate.	Average daily range.	Average pulse-rate.		Average daily range.	Average pulse rate.	Average daily range.	Average pulse-rate.
E. O.	12	66	..	..	H. L. K..	51	75	..	..
A. W. S..	7	71	..	..	A. H. M..	23	60	19	53
J. F. S...	23	78	..	..	H. R. D..	32	70	32	71
J. C. W..	29	68	16	60	E. H. B..	24	62	11	55
B. F. D..	10	53	17	59	B. N.	12	65	..	..
H. C. K..	18	50	28	63	G. E. B..	7	75	..	..
A. L. L...	30	64	10	57	A. W. W.	16	62	13	60
S. A. B..	17	68	17	61	W. E. T..	14	69	11	73
N. M. P..	48	78	34	65	H. B. W.	23	59	12	65

COMPARISON OF PULSE-RATE AS DETERMINED BY DIFFERENT METHODS.

Since in a very large number of experiments the subjects counted the pulse themselves, it is important to determine to what extent one can rely upon the pulse-rate counted by a subject inside the respiration chamber as indicating the true pulse-rate. For purposes of comparison, a number of experiments were made in which the subject counted his own pulse-beat and simultaneous observations were made outside of the chamber by an attendant, either by means of a pneumograph or, very recently, by a stethoscope. This series of experiments was somewhat extended in nature and was made with 10 subjects. The results are collected for comparison in table 53.

While there are fluctuations both ways, in general it appears that the count as registered by the subject is apt to be somewhat lower than that obtained from the pneumograph. Whether the rate is actually decreased while the subject is counting the pulse, or whether the lower figure is obtained by error in counting we can not as yet tell. In the experiments made in 1908 and 1909, recorded in table 53, the results show likewise wide differences, although here, with the exception of the subject F. R., the pulse-rates as counted by the subject were invariably somewhat higher than those indicated by the apparatus. We are inclined to consider the low figures obtained by F. R. on himself in the experiment of December 15 and December 21, as due to inexperience in counting the pulse. These latter experiments, then, would imply that the differences noted in the preceding portion of the table were due not to an actual difference in the pulse-rate so much as to inability on the part of the subject to count the pulse carefully.

TABLE 53.—*Comparison of pulse-rate by subject with pulse-rate by pneumograph or stethoscope.*

Subject and date	Period	Pulse-rate by subject. No. of observations.	Pulse-rate by subject. Average.	Pulse-rate with apparatus.[1] No. of observations.	Pulse-rate with apparatus.[1] Average.
1907.					
A. H. M.:					
Mar. 9	$9^h 00^m$ a.m. to $5^h 00^m$ p.m.	11	47	15	51
Apr. 29	8 44 a.m. 4 44 p.m.	14	53	23	60
May 15	8 57 a.m. 4 57 p.m.	7	66	21	69
May 24	9 24 a.m. 5 24 p.m.	8	62	17	63
H. B. W.:					
Apr. 26	12 00 noon 4 05 p.m.	9	55	10	65
W. E. T.:					
Apr. 27	8 04 a.m. 4 04 p.m.	15	72	20	69
May 3	8 31 a.m. 4 31 p.m.	16	74	26	73
A. W. W.:					
May 2	8 24 a.m. 4 24 p.m.	10	52	26	61
May 9	1 00 p.m. 4 25 p.m.	8	55	10	56
May 25	8 17 a.m. 4 17 p.m.	16	55	24	64
May 28	8 12 a.m. 11 52 a.m.	9	57	14	61
E. H. B.:					
May 14	8 24 a.m. 4 24 p.m.	14	62	21	59
1907.					
A. L. L.:					
May 4	$8^h 15^m$ a.m. to $4^h 15^m$ p.m.	15	52	25	59
May 13	8 18 a.m. 4 18 p.m.	12	67	24	63
May 27	8 30 a.m. 4 30 p.m.	13	59	19	61
1908.					
J. R.:					
Dec. 4	4 45 p.m. 5 45 p.m.	4	70	6	68
Dec. 17	9 01 a.m. 3 01 p.m.	14	67	21	64
F. R.:					
Dec. 15	8 47 a.m. 2 47 p.m.	12	55	18	62
Dec. 21	9 13 a.m. 3 13 p.m.	12	55	20	66
1909.					
Jan. 7	9 00 a.m. 3 00 p.m.	13	53	[2] 8	[2]54
1908.					
F. M. C.:					
Dec. 16	9 18 a.m. 3 18 p.m.	10	69	18	65
1909.					
L. E. E.:					
Jan. 8	9 18 a.m. 2 18 p.m.	9	57	19	56

[1] After Dec. 9, 1908, stethoscope was used.
[2] No record (with stethoscope) from $11^h 10^m$ a. m. to $12^h 30^m$ p. m.

PULSE-RATE AS INDEX OF METABOLISM.

Many of the experiments made by us thus far indicate that under varying conditions of muscular activity and diet, the pulse-rate is more or less parallel to the total metabolism. While it can not be stated as a definitely fixed rule that a given pulse-rate accompanies a given metabolism, it has been shown in a discussion in a previous report that with the same subject, under like conditions of muscular activity, the pulse-rate during a 7-day fast appeared to be an excellent index of the total metabolism. When it is realized that the pulse-rate as counted in those experiments was obtained by the subject, and hence liable to some error, it is seen that the opinion there expressed that there should be a more careful study of the relationship between pulse and total metabolism, can not be over-emphasized. Even if the body is quiet and without food, two very important factors in the total metabolism are the internal muscular work and muscular tonus. At present the most practical method of measuring internal muscular work, or tonus, or more properly speaking, the most practical method of measuring differences in the internal muscular work or tonus is by measuring the pulse-rate.

It appears, therefore, that in metabolism experiments in the future, special attention should be paid to accurate continuous records of the pulse-rate, as

indicating in a general way the internal muscular work and muscular tonus.[1] As these two factors apparently in large measure determine the total metabolism during rest, the pulse-rate can under these conditions be taken as a reasonably satisfactory index of the total metabolism. Experiments are much needed, using the same subject under widely varying conditions of pulse-rate. That the observation of the pulse-rate should also be accompanied by a measurement of blood-pressure is obvious, and it is probably true that a simultaneous study of the pulse-rate, blood-pressure, respiration, and total metabolism will show some most interesting relationships which may prove of direct practical value to the practising physician.

WATER VAPORIZED FROM LUNGS AND SKIN.

EARLIER INVESTIGATIONS.

The determination of the water vaporized from the human body has been attempted with but few forms of apparatus, and the insensible perspiration or the loss in weight has of necessity been taken by many writers as the most available index regarding the amount of water vaporized from the body.

In their classical contribution to our knowledge of the metabolism of normal man, Pettenkofer and Voit[2] made a number of experiments in which they determined the water-vapor output of resting man. They obtained from 828 to 1207 grams in 24 hours, an average of 965 grams, or 40 grams per hour. With fasting man they found as an average of 2 experiments, 822 grams per 24 hours, and they record that while there was an actual increase on the days when food was taken, the increase was not as large as they would have expected.

An early research in metabolism that includes measurements of the water vaporized from the body is the little known study of Sadovyen.[3] Using the Pashutin respiration apparatus, on one day he found 1700 grams of water-vapor in 24 hours, from a man, with food, having a body-weight of 79 kilos. On 2 other days, both of which were fasting, the subject gave off 961 and 831 grams of water-vapor, respectively. Another day with food showed an output of 1265 grams of water-vapor. In a second experiment (fasting) which continued for 4 days, the water-vapor output was 730, 709, 597, and 713 grams on the 4 consecutive days, respectively. On 1 day of food following fast the subject, with a body-weight of 75 kilos, gave off 1435 grams of water-vapor. In another series of experiments, when considerable quantities of starch and sugar were taken, the subject, with a body-weight of 79 kilos, gave off on 1 day 1579 grams of water-vapor and on a second day 1137 grams. In another experiment with the same subject, with a body-weight of 77.5 kilos, he gave off 938 grams of water-vapor for 24 hours. The author makes the interesting conclusion that 50 per cent less water is vaporized during fasting than with food.

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[1] For a further discussion of this subject see p. 248.
[2] Pettenkofer and Voit, Zeitschr. f. Biol., 1866, 2; p. 459.
[3] Sadovyen, Publications of the Russian Society of General Hygiene, St. Petersburg, 1887–88, 12; p. 13.

Several years later, Likhatscheff,[1] working with the same respiration apparatus, determined in a series of experiments with 2 individuals the quantity of water vaporized from the lungs and skin in 24 hours. With one subject, A. D. P., 24 years of age, weight 58.4 kilos, there were 775.5 grams of water vaporized. With the same subject, with a body-weight of 58.2 kilos, there were 880 grams of water-vapor, and in 2 subsequent experiments with the same subject, with a body-weight of 57.28 and 55.82 kilos, respectively, there were collected 843 and 664 grams of water-vapor, respectively. In the last experiment, A. D. P. fasted. With another subject, G. N. K., 24 years old, weighing 64.8 kilos, there were 1049 grams of water vaporized in 24 hours. In a second experiment with this same subject, weighing 66.4 kilos, there were 805.5 grams of water vaporized. In none of these experiments are the data presented in sufficient detail to permit a calculation of the relative humidity. The temperatures were all not far from 20° C.

Some of the most important researches on the water vaporized from the lungs and skin have been made by Rubner and his associates. The majority of their experiments were made for the purpose of studying the influence of some special factor upon the water vaporized, such as the influence of humidity, body-temperature, and, indeed, experiments were made with negroes to study the possible effect of racial characteristics. From these experiments a number can be selected giving data that are comparable with those here reported. In studying 7 persons at rest, Wolpert[2] found that the hourly production of water-vapor, calculated to a uniform body-weight of 70 kilos, varied from 30.9 to 70.9 grams; 4 of the 7 subjects vaporized from 56 to 60 grams of water per hour at a temperature of 18° C., with a relative humidity of from 35 to 60 per cent.

Studying a negro, Rubner[3] found that with a body-weight of 67 kilos at a temperature of 26.4° C., the subject gave off 56.5 grams of water per hour. The temperature was, however, somewhat above the temperatures in the experiments here reported.

Laschtschenko,[4] in Rubner's laboratory, studying the influence of the ingestion of water on the water-vapor elimination, made a number of experiments at temperatures of 17° to 19° C. The relative humidity was from 25 to 55 per cent. In 4 experiments he found the water vaporized, calculated to a body-weight of 70 kilos to be 30, 23, 20.8, and 28.2 grams per hour, respectively, when no drinking-water was consumed. In 2 experiments when drinking-water was taken, the water vaporized per hour was 21.6 and 30.5 grams, respectively.

Schattenfroh,[5] in Rubner's laboratory, making respiratory experiments on a fat man, 53 years old and weighing without clothing 95 kilos, found that at

[1] Likhatscheff, Production of heat by healthy man in the condition of comparative rest. Dissertation (Russian), St. Petersburg, 1893.
[2] Wolpert, Archiv f. Hygiene, 1896, **26**, p. 100.
[3] Rubner, Archiv f. Hygiene, 1900, **38**, p. 133.
[4] Laschtschenko, Archiv f. Hygiene, 1898, **33**, p. 145.
[5] Schattenfroh, Archiv f. Hygiene, 1900, **38**, p. 93.

a temperature of 20° C. and a relative humidity of 40 per cent, there were on the average 91 grams of water vaporized per hour. With a relative humidity of 65 per cent, 1 experiment showed that 31.6 grams of water were vaporized per hour.

In a general summary of this topic, Rubner[1] has collected some of the data obtained by his associates. On 1 person, F., with a body-weight of 71 kilos, at a temperature of 14° C., there were 45 grams of water vaporized per hour; at 17.4° C., 29.6 grams; and at 23.5° C., 54.4 grams.[2] Another subject, H., weighing 58 kilos, well nourished, showed in a series of experiments with widely varying relative humidity, at 15° C., 36.3 grams per hour in dry air (8 per cent humidity) and 9 grams per hour in moist air (84 per cent humidity); at 20° C., the quantities were 54.1 and 15.3 grams, respectively, and at 23° C. they were 72.8 and 18.7 grams, respectively.[3]

One of Rubner's associates, Wolpert, made a large number of experiments with the subject, Br., whose body-weight was 58 kilos. In the winter time, with summer clothing, he gave off, at 15° to 20° C. temperature, 19 grams of water-vapor per hour, an unusually low amount.

In connection with an extended series of experiments with a large respiration chamber in Stockholm, Sondén and Tigerstedt[4] determined the water vaporized for a number of individuals. The accuracy of their determinations of water has been called into question by the authors themselves and leaves considerable to be desired. Nevertheless, the results have an interest. Of the experiments with the large number of different individuals studied, those most comparable with the experiments here reported are with a group of men 19.5 to 23 years of age with which there were 2 experiments (6 subjects in each experiment), where the water-vapor per hour was found to be 46 grams.

EXPERIMENTS ON THE WATER VAPORIZED FROM LUNGS AND SKIN.

METHOD USED AND ACCURACY OF DETERMINATIONS.

In the respiration calorimeter at Wesleyan University direct determinations of the water vaporized from the body were made in practically all experiments, and they furnish by far the most satisfactory data for deducing the normal water-vapor output of resting man living under the conditions obtaining inside the respiration chamber, and furnish evidence for a discussion of the significance of the water-vapor elimination, its fluctuations and the factors that affect it. In nearly all of the experiments recorded herewith, and in the large majority of those made previously with the same apparatus and recorded in other publications, the water vaporized was determined with considerable accuracy. This is particularly true in rest experiments. The method of bringing away the

[1] Rubner, Die Gesetze des Energieverbauchs bei der Ernährung, Leipsic and Vienna, 1902, p. 203 *et seq.*
[2] Rubner, Archiv f. Hygiene, 1900, **38**, p. 133.
[3] Rubner and v. Lewaschew, Archiv f. Hygiene, 1897, **29**, p. 33.
[4] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 99.

heat from the calorimeter, namely, the passing of cold water through a pipe inside the chamber, may result in the condensation of considerable moisture upon this pipe, particularly if the water vaporized from the lungs and skin is large in amount. This is invariably the case in work experiments, but in rest experiments, under proper conditions of ventilation, the relative humidity of the air inside the chamber is usually fairly low, and the "dew-point" is as a rule considerably below 10° C. Inasmuch as the ingoing water is commonly kept at a temperature above 10° C. during rest experiments, there is rarely condensation upon these pipes. Finally, provision was made for actually weighing the heat-absorbing system and noting the weight of water condensed upon it. The difficulties attending the weighing of this apparatus which have been elsewhere described,[1] were very great, however, and the results for water vaporized, which in some publications have been corrected for these weights, must of necessity have less value than the results for those experiments in which there was no condensation upon the heat-absorbing system.

In this connection it is of great importance to note in these experiments that the chief value in determining the water-vapor in the outcoming air-current has been to compute accurately the amount of heat that was required to vaporize the water, since the heat measurements were of prime importance in our experiments. It is obvious that if water is vaporized from the body and subsequently condensed upon the absorbers, no interchange of heat so far as the calorimeter as a whole is concerned has taken place. A certain amount of heat, to be sure, has been required to vaporize the water as it leaves the body, but an equal amount of heat was yielded to the heat-absorbing system as the water was condensed upon it. Consequently no errors in the heat measurement occur, even if there be considerable condensation of water upon the cooling pipes of the heat-absorbing system.

Such condensation does, however, interfere seriously with the accurate determination of the water vaporized from the lungs and skin, a problem entirely independent of the heat measurement. Accordingly it is possible to discuss intelligently only the results obtained in those experiments in which there was no condensation, namely, those during rest. In some of the previously recorded work experiments, where the amount of water vaporized was very considerable, doubtless the errors incidental to weighing the heat-absorbing system and the corrections thereby applied to the water collected in the sulphuric-acid-absorbing vessels were proportionately not large, inasmuch as large quantities of water were being dealt with. In the rest experiments, where the water vaporized per hour is not far from 40 grams, the condensation of 40 grams of water on the heat-absorbing system introduces considerable error. In controlling these experiments it was planned so to adjust the conditions of ventilation and the temperature of the ingoing water that condensation on the pipes would be avoided in all instances.

[1] Atwater and Benedict, *loc. cit.*, p. 161.

The large surface of the body and the hygroscopic nature of the clothing about the person make it extremely difficult to state absolutely what is the weight of water-vapor leaving the body itself. It is impossible from the water determinations to distinguish between 1 gram of water vaporized from the lungs or skin of a man and 1 gram of water vaporized from the clothing. The problem of determining exactly the water vaporized from the lungs and skin of the man is extremely complicated. It is necessary to take into consideration the moisture-content of the clothes, the muscular activity of the individual, the relative humidity [1] of the air, the temperature of the air and of the body, and probably other as yet unknown factors. Investigations of this nature are highly desirable, and until such an investigation is carried out we must content ourselves with the results obtained in the experiments thus far made, which are admittedly somewhat crude.

In the experiments, the subject sits in an arm-chair or lies on a cot-bed inside the respiration chamber; he is covered with clothing of a more or less hygroscopic nature and makes relatively slight muscular movement. While, as a rule, sudden and marked changes in the relative humidity are not common, the humidity may change considerably in a short time. The results deal only with the water vaporized from the lungs and skin, or the water-vapor that left the respiration chamber and was carried by means of the air-current to the sulphuric-acid vessels, due corrections being made for the variations in water-vapor present in the chamber at the beginning and end of the several periods. No water in the urine, drink, feces, or food is taken into consideration.

WATER VAPORIZED DURING WAKING HOURS.

The water-vapor eliminated during the waking hours by different subjects has been collected in table 54, in which the subjects are placed in the order of their body-weights. For purposes of comparison and for use in the general discussion of many of these results, an abstract of the body-measurements is given in that the body-weight and height of each subject are shown in the table. The water-vapor eliminated per hour, the amount per kilo per hour, and the amount per square meter of body surface per hour, are likewise shown for each subject, these figures being the average of several experiments with each man. The total amount eliminated per hour varies considerably among the different subjects, the highest being 52.7 grams with W. E. D., and the lowest 25.7 grams with H. R. D. The average of all experiments is 38.7 grams per hour. The temperature of the chamber was 19° to 21° C. The relative humidity varied from 30 to 55 per cent, but in the larger number of experiments it was about 50 per cent.

[1] Rubner and his associates have taken up the problem from the hygienic standpoint, and their results are of great general interest, though open to criticism. (See Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 433.)

TABLE 54.—*Water vaporized during waking hours by different individuals in rest experiments.*

Subject.	Body-weight (without clothing).	Height.	Water vaporized.			Subject.	Body-weight (without clothing).	Height.	Water vaporized.		
			Per hour.	Per kilogram per hour.	Per square meter of body surface[1] per hour.				Per hour.	Per kilogram per hour.	Per square meter of body surface[1] per hour.
	Kilos.	*cm.*	*Gms.*	*Gram.*	*Gms.*		*Kilos.*	*cm.*	*Gms.*	*Gram.*	*Gms.*
H. C. M...	86.3	166	47.4	0.55	19.7	H. A.	64.1	170	45.3	0.71	23.0
W. O. A...	84.8	168	36.3	.43	15.3	J. F. S....	63.4	171	35.6	.56	18.2
F. G. B...	83.2	183	41.3	.50	17.6	W. H. L..	63.2	174	42.0	.67	21.6
D. W.	77.4	180	36.2	.47	16.3	J. V. C....	63.2	173	43.6	.69	22.4
G. G. R...	77.2	178	43.4	.56	19.5	G. E. H...	63.2	179	33.5	.53	17.2
J. C. W...	75.8	178	36.7	.48	16.6	J. N. T....	63.1	173	40.5	.65	20.8
S. C. D...	74.9	178	44.1	.59	20.2	D. R. F...	62.4	173	32.5	.53	16.8
W. R. L...	74.9	198	43.2	.58	19.7	A. G.	62.3	170	40.5	.65	21.0
W. E. D...	74.4	179	52.7	.71	24.2	C. F. B....	62.2	170	39.3	.63	20.4
F. C. B....	73.6	183	46.5	.63	21.5	J. W. H...	60.9	175	46.7	.77	24.6
H. C. K...	72.6	181	35.4	.49	16.6	J. A. R....	59.2	180	31.9	.55	17.1
H. F.	71.2	168	29.7	.42	14.0	C. A. R...	59.0	174	38.6	.66	20.7
A. L. L...	70.8	166	34.9	.49	16.6	H. C. A...	58.9	172	29.6	.51	15.9
R. D. M...	70.4	178	40.7	.58	19.3	F. W. H..	58.4	173	43.4	.74	23.3
A. W. S...	69.4	176	35.7	.51	17.2	F. N. C...	57.6	168	34.7	.60	18.9
J. R.	69.2	183	39.5	.57	19.0	H. R. D...	57.5	171	25.7	.45	14.0
N. M. P...	69.1	177	38.2	.55	18.4	H. E. S...	57.2	178	27.3	.48	14.9
E. O.	68.4	173	36.5	.54	17.8	S. A. B....	56.4	166	26.7	.47	14.7
A. M.	66.9	175	43.7	.66	21.6	J. T. H...	56.0	170	38.4	.69	21.3
B. F. D...	66.4	170	44.8	.68	22.2	H. L. K...	55.6	166	34.9	.63	19.5
C. R. Y...	66.4	170	38.0	.58	18.9	F. E. R...	52.2	168	40.7	.78	23.8
H. D. A...	66.2	181	44.1	.67	22.0	H. L. W..	51.8	164	40.8	.79	23.8
N. B.	66.0	172	39.7	.60	19.8	G. H. H...	51.7	163	34.9	.68	20.4
R. A. M...	65.0	166	47.7	.74	24.0	G. W. S...	51.5	173	35.5	.70	20.8
A. H. M...	64.3	179	29.0	.45	14.7	T. M. C...	50.5	166	33.6	.67	20.0
H. A. P...	64.3	180	46.5	.72	23.6	H. G.	49.2	160	32.6	.66	19.8
F. L. T...	64.3	192	42.0	.65	21.2	B. N.	46.4	168	46.4	1.00	29.2
E. M. S...	64.3	175	39.9	.62	20.2	Avge. ..	...	....	38.7	.61	19.7

[1] In computing body-surface the formula of Meeh has been used: $12.312 \sqrt[\frac{3}{2}]{\text{body-weight}}$.

Per kilogram per hour.—Upon the assumption that the larger body would eliminate a larger amount of water-vapor, it is customary to compare results with different individuals of different body-weight by calculating the results on the basis of per kilogram of body-weight per hour. The results of the water-vapor determinations with the respiration calorimeter at Wesleyan University have likewise been computed on this basis and they show again wide variations, ranging from 1 gram per kilogram per hour in the case of a young man, B. N., to 0.42 gram per kilogram per hour with the subject H. F. The average of all experiments was 0.61 gram per hour.

Per square meter of body-surface per hour.—Inasmuch as the water-vapor is continually being given off from the surface of the body, it is reasonable to suppose that there would be an approximate relationship between body-surface and the water vaporized. Consequently it is important to compare the different experiments with different subjects on the basis of per square meter of body-surface per hour. The area of the body-surface has been computed according to the well-known formula of Meeh,[1] or $S=K\sqrt[\frac{3}{2}]{W}$, in which K for man =

[1] Meeh, Zeitschr. f. Biol., 1879, **15**, p. 425.

12.312 and *W* is the body-weight. Even calculating the results on a supposedly common basis, we find variations in the amounts vaporized per square meter of body-surface per hour ranging from 14 grams with H. R. D. to 29.2 grams with B. N. The average value is 19.7 grams per hour.

WATER VAPORIZED DURING SLEEP.

During sleep when the subject is lying quietly in bed with light covering, perhaps the best conditions for studying the water-vapor output obtain. In the experiments reported the subjects usually went to bed at 11 p. m.; the absence of muscular activity during the following 2 hours resulted in constant conditions with regard to temperature and moisture inside the chamber at 1 a. m., and this constancy makes all such experiments more strictly comparable. While, then, there are fewer subjects with whom the water-vapor output during sleep has been studied, we believe that the results of experiments made during this period are more comparable with each other, especially on the basis of body-weight or body-surface, than with experiments made under any other conditions heretofore obtained. The average results for 17 individuals have been collected in table 55. As in the preceding table, the subjects have been arranged in the order of the body-weights. Since in experiments with muscular work, the preceding muscular activity may have a possible influence upon the body of the subject and there may be an accumulation of large amounts of condensed water on the heat-absorbing system inside the chamber, we have here selected only those experiments in which the sleep followed rest to compare with experimental periods during the waking hours when the subject did no muscular work and was at rest.

TABLE 55.—*Water vaporized during sleep by different individuals, after rest (1 a. m. to 7 a. m.).*

Subject.	Water vaporized.			Subject.	Water vaporized.		
	Per hour.	Per kilogram[1] per hour.	Per square meter of body-surface[2] per hour.		Per hour.	Per kilogram[1] per hour.	Per square meter of body-surface[2] per hour.
	Grams.	*Gram.*	*Grams.*		*Grams.*	*Gram.*	*Grams.*
W. O. A.....	34.9	0.41	14.7	C. R. Y.....	44.5	0.68	22.2
D. W.	27.7	.36	12.4	J. F. S......	30.9	.49	15.8
J. C. W......	36.2	.48	16.5	A. H. M.....	25.4	.41	13.2
H. C. K.....	30.3	.42	14.2	H. R. D.....	25.1	.44	13.8
H. F.	30.9	.43	14.6	S. A. B.....	26.9	.47	14.7
A. L. L......	35.4	.50	16.8	H. E. S.....	29.2	.52	16.2
A. W. S.....	33.5	.48	16.1	H. L. K.....	28.6	.52	16.0
E. O.	38.1	.56	18.8				
N. M. P.....	29.9	.45	14.8	Average ..	32.1	.48	15.9
B. F. D.....	38.9	.59	19.3				

[1] The body-weights are practically those given for the same subjects in table 54, although there are certain variations, especially with the subjects N. M. P. and A. H. M.
[2] In computing body-surface the formula of Meeh has been used: $12.312 \sqrt[3]{\text{body-weight}}$.

The wide discrepancies noted in table 54 are here conspicuously absent, for the extreme range in the results for the water vaporized per hour is only from 25.1 grams with H. R. D. to 44.5 with C. R. Y. The latter value is unusually high, but 4 experiments with this subject gave practically the same results in all cases. The average output of water-vapor is 32.1 grams per hour. Computed on the basis of per kilogram of body-weight, the variations are from 0.36 with D. W. to 0.68 with C. R. Y., and the average value is 0.48 gram. Per square meter of body-surface the water vaporized per hour ranges from 12.4 grams with D. W. to 22.2 grams with C. R. Y., the average value being 15.9 grams.

COMPARISON WITH OTHER INVESTIGATIONS ON WATER VAPORIZED DURING SLEEP.

While from the conditions under which these experiments were made, it is difficult to compare them with the results of other experiments, it may be of interest to see in how far our results confirm those obtained previously.

Lewin,[1] using the Pettenkofer chamber in Munich, made 5 experiments on the water-vapor output of man while asleep. The amounts per hour were 22.9, 32.5, 28.7, 31.1, and 31.7 grams, respectively. In these experiments, however, no notes were made as to whether the clothing was weighed before and after the experiment, so the total exhalation of water can not be found.

Working with the respiration calorimeter of Pashutin, Likhatscheff and Avroroff studied the water vaporized per hour with a young woman who had intermittent malarial fever.[2] The observations reported as "normal" were taken on a day when no fever was present. The subject was 17 years of age and weighed 50 kilos. The water eliminated per hour as water-vapor averaged 29 grams during the 22 hours. The lowest output was 24.5 grams per hour between the hours of 5 and 7 a. m., when the subject was asleep and the highest 33 grams per hour between 9 and 11 p. m. when awake and reading.

Using the Jaquet respiration apparatus at Basel with a special attachment for studying directly the water vaporized, Staehelin[3] determined the water vaporized by man in experiments during the night, both after fasting and after various diets. In 5 experiments of 12 hours each the water vaporized in the chamber and passing out in the air-current was 254, 285, 280, 286, and 289 grams, respectively. By weighing the bed and bedding he also attempted to obtain the amount of water absorbed by these articles and thus determine the total water vaporized from the body of the man. In the 5 experiments the increase in weight of the bed and bedding, calculated as water, was 78, 101, 36, 88, and 201 grams, respectively. Assuming this as water vaporized from the body of the subject but subsequently condensed on the clothing, the total water vaporized from the body in the 5 experiments is 332, 386, 316, 374, and

[1] Lewin, Zeitschr. f. Biol., 1881, **17**, p. 75.
[2] Likhatscheff and Avroroff, Reports of the Imperial Military Medical Academy, St. Petersburg, 1902, **5**.
[3] Staehelin, Zeitschr. f. klin. Med., 1906, **66**, p. 201.

490 grams, respectively, during a 12-hour experiment in the night. During the whole experiment the subject was in bed, covered with bed-clothing, and lying quietly and for the most part asleep. The temperature of the chamber varied from 17.4° to 19.1° C.

RELATIVE AMOUNTS OF WATER VAPORIZED FROM THE LUNGS AND SKIN.

METHOD OF COMPUTATION.

The water vaporized from the body of a subject inside the respiration chamber is made up in part of water vaporized from the skin, and in part of water taken up by the air inspired into the lungs. It is of interest to secure evidence with regard to the partition of this water between that vaporized from the lungs and that from the skin. Thanks to a method of computation presented by Zuntz,[1] we are able to make an approximate estimation of these relative proportions.

Assuming that the air inspired has the moisture-content of the air in the chamber and that the expired air is saturated[2] with moisture at the temperature of the body, 37° C., it is possible, if we know the total ventilation of the lungs, to compute the output of water-vapor through the lungs. In our experiments the total ventilation of the lungs was not directly determined, as it is in the experiments with the Zuntz apparatus. As a result of a number of experiments with trained subjects with the Zuntz apparatus, Zuntz and his associates found that, for every liter of oxygen absorbed, there was a ventilation of the lungs of 21 liters of air, and hence if we multiply the volume of oxygen absorbed in these experiments by 21, we have an approximate measure of the total ventilation of the lungs. This calculation has been carried out with many of the experiments here reported, and the apportionment of the water-vapor between the lungs and skin has been made upon this basis. Obviously there are many chances for error in a computation of this kind, since the ratio of oxygen absorbed to the total ventilation varies somewhat with different subjects even at rest, but averaging the results of a large number of experiments, such as are here collected, the values are probably fairly representative of the true ventilation conditions.

It has been found in the majority of our experiments that the respiration-rate varies little from hour to hour, and consequently there will be a reasonably constant elimination of water-vapor through the expired air. Where there are variations in respiration rate, there may be a larger amount of air taken into the lungs and consequently a greater amount of water carried out with the saturated air. It is still to be proved, however, that with an increased respira-

[1] Zuntz, Loewy, Müller, and Caspari, Höhenklima und Bergwanderungen, Berlin, 1906, p. 380.

[2] At rest this is probably true. With the forced respiration accompanying muscular work, Rubner and Lesage maintain that the expired air is not saturated. (See discussion of this point by Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 436.)

tion-rate there is an actual larger ventilation of the lungs, since with deep, slow breathing, there may be the same volume of air carried into the lungs in a given time as with rapid, shallow breathing.

Rubner[1] reports an experiment in which a man breathed into a specially designed headpiece, and the water-vapor from the lungs per hour during rest was found to be 17 grams. At rest, with deep breathing, the amount was but 19 grams per hour, indicating that the increased depth of respiration is not accompanied by a considerable increase in the total volume of expired air. It is interesting to note, furthermore, that in many of the experiments made by Zuntz where work was performed, although the ventilation in the lungs increased very considerably as noted on the dial of the gas-meter, there was likewise an increase in the oxygen consumption. In the majority of cases the ratio between the oxygen consumed and the total ventilation of the lungs remained not far from that found during resting experiments. This would point strongly, therefore, towards the reliability of using the oxygen intake as a factor, which when multiplied by the factor 21, gives the total ventilation.

The difficulties attending experimentation of this kind are considerable, and the admirable researches of Rubner on the water-vapor output, and Zuntz on the volume of respiration of the lungs, should be supplemented by researches which will show more clearly and more exactly the water-vapor exhaled from the lungs under different conditions of respiration. At present in these experiments it is necessary to assume that the rate of respiration and the depth of respiration did not materially vary throughout the experiment.

The interesting studies of Willebrand[2] were made with a subject without clothing, and are comparable with a number of previous observations which were made by Schierbeck[3] under similar conditions, for which we can hardly find place in this discussion. Willebrand's conclusions are that the water elimination through the skin during complete rest increases slowly and proportionately to the temperature of the surrounding air, beginning at 12° C. and going to a point where sensible perspiration appears.[4]

The proportions of water-vapor eliminated from the lungs and skin of fasting man have been discussed on the basis of the Zuntz calculation in considerable detail in a previous publication.[5] It was there pointed out that the proportions between the lungs and skin did not vary materially with the same individual whether he was taking food or was without food and on the average with resting man 44 per cent of the water vaporized was from the lungs.

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[1] Rubner, Archiv f. Hygiene, 1898, **33**, p. 151.
[2] Willebrand, Skand. Archiv f. Physiol., 1902, **13**, p. 337.
[3] Schierbeck, Archiv f. Hygiene, 1893, **16**, p. 203.
[4] For the literature of the subject, see the article by A. J. Kalmann, Ueber die Beeinflussung der Wasserdampfabgabe der Haut durch klimatische Faktoren, durch Muskelarbeit und Bäder, Archiv f. d. ges. Physiol., 1906, **112**, p. 561.
[5] Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 437.

APPORTIONMENT TO LUNGS AND SKIN DURING WAKING HOURS.

The relative amounts of water vaporized from the lungs and skin during waking hours in the experiments reported in the first part of this publication, as well as in many of the earlier experiments, have been computed and tabulated in table 56. The method of computing one experiment is here given.

TABLE 56.—*Proportions of total water vaporized from the lungs and skin, respectively, during waking hours in rest experiments.*

Subject.	Proportion of water vaporized.		Subject.	Proportion of water vaporized.		Subject.	Proportion of water vaporized.	
	From lungs.	From skin.		From lungs.	From skin.		From lungs.	From skin.
	P. ct.	*P. ct.*		*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*
H. C. M....	32.3	67.7	H. D. A....	37.4	62.6	H. C. A....	44.9	55.1
W. O. A....	44.7	55.3	N. B.	36.9	63.1	F. W. H....	29.7	70.3
F. G. B.....	36.7	63.3	R. A. M....	30.1	69.9	F. N. C.....	41.1	58.9
D. W.	45.6	54.4	H. A. P....	26.2	73.8	H. R. D....	51.4	48.6
G. G. R....	32.3	67.7	A. H. M....	43.3	56.7	H. E. S.....	44.6	55.4
S. C. D.....	32.7	67.3	F. L. T.....	38.8	61.2	S. A. B.....	50.9	49.1
W. R. L....	35.7	64.3	E. M. S....	31.7	68.3	J. T. H.....	33.6	66.4
W. E. D....	28.9	71.1	H. A.	37.7	62.3	H. L. K....	40.3	59.7
F. C. B.....	34.0	66.0	W. H. L....	31.8	68.2	F. E. R.....	28.0	72.0
H. C. K....	41.0	59.0	J. V. C.....	31.3	68.7	H. L. W....	30.2	69.8
H. F.	45.3	54.7	G. E. H....	33.6	66.4	G. H. H....	40.4	59.6
A. L. L.....	41.7	58.3	J. N. T.....	36.7	63.3	G. W. S....	34.3	65.7
R. D. M....	33.2	66.8	D. R. F.....	41.1	58.9	T. M. C....	37.5	62.5
J. R.	39.2	60.8	A. G.	35.7	64.3	H. G.	35.1	64.9
N. M. P....	40.9	59.1	C. F. B.....	41.3	58.7	B. N.	26.4	73.6
A. M.	37.0	63.0	J. W. H....	34.1	65.9	Miss S.	21.0	79.0
B. F. D.....	32.6	67.4	J. A. R.....	38.6	61.4	Miss B.	21.4	78.6
C. R. Y.....	38.2	61.8	C. A. R....	33.6	66.4			
						Average .	36.3	63.7

During the waking hours in the experiment of April 18, 1903, W. O. A., absorbed 276.6 liters of oxygen. According to the Zuntz factor, 21, the total ventilation of the lungs during this period was therefore 5809 liters. In order to know the amount of water-vapor taken into the lungs by the air, it is necessary to know the absolute moisture-content of the air inspired. This is obtained from an analysis of the residual air in the chamber. It was found that during the waking hours of this experiment the average quantity of water-vapor remaining in the chamber was 48.7 grams. The volume of the chamber was approximately 4900 liters. The total water in the air inspired may, therefore, be obtained as follows: $48.7 \div 4900 \times 5809 = 57.7$. Consequently, during this period it is considered that the inspired air contained 57.7 grams of water-vapor. In order to compute the amount of water-vapor expired, it is assumed that the air leaving the lungs is saturated at the temperature of the human body, namely, 37° C. One cubic meter of air saturated with water-vapor at 37° C. contains 43.465[1] grams of water, and the total amount exhaled by the man is computed as follows: $43.465 \times 5809 \div 1000 = 252.5$. The total amount of water-vapor leaving the body in the exhaled air is, then, 252.5 grams. Deducting from this the amount in the air inspired, namely, 57.7 grams, we have as the total amount of water-vapor leaving the lungs, 194.8

[1] Smithsonian Physical Tables, Washington, 1896, p. 155.

grams. The water vaporized and leaving the chamber in the air-current, making due allowance for the variations in the water-vapor residual in the air of the chamber, showed that during the period of waking hours this subject gave off 436 grams of water. From the above calculation it is seen that 194.8 grams has been computed as having been exhaled from the lungs and consequently the difference, 241.2 grams, is computed as having been vaporized from the skin. Of the total amount exhaled, therefore, 44.7 per cent was vaporized from the lungs and 55.3 per cent was vaporized from the skin. The other experiments were calculated in the same way, and a summary of the results is given in the table.

An examination of table 56 shows that there are wide variations in the percentages of the water-vapor leaving the lungs and skin. The lowest percentage of water-vapor leaving the lungs is 21 with Miss S. The other woman subject, Miss B., also shows a low percentage. The highest result is that with the subject H. R. D., since 51.4 per cent of the total water vaporized was computed as being vaporized from the lungs. Leaving out of discussion the 2 experiments with women, the lowest percentage of water-vapor leaving the lungs in experiments with men is that found for H. A. P., *i. e.*, 26.2 per cent. The average of the results with 53 subjects at rest shows that 36.3 per cent of the total water vaporized leaves the body as aqueous-vapor in the expired air.

While the data regarding women are admittedly too meager for generalization, the results are suggestive of numerous lines of research as to the relations of the vaporization of water from the lungs and skin as affected by the dress of women, the possible influence of wearing corsets on the ventilation of the lungs, and the influence of the larger preponderance of subcutaneous fat[1] upon the water vaporized from the skin.

APPORTIONMENT TO LUNGS AND SKIN DURING SLEEP.

On the general principle that during sleep all metabolic functions are more nearly on a level, there is less muscular activity, and the general conditions of the experiment are much more satisfactory for comparison, the experiments during the night period (1 a. m. to 7 a. m.) have been collected with the view of studying the proportions of water vaporized from the lungs and skin under conditions of the unusual quiet obtaining during sleeping hours. The method of computation is exactly that outlined on page 146. The results are recorded in table 57 herewith.

The striking feature of the results obtained during the sleeping hours is that the proportion of water computed as vaporized from the lungs is essentially that found during the waking hours, and apparently it is immaterial whether the subject is sitting up awake or lying quietly asleep as to the relative amounts of water vaporized from the lungs and skin, provided that the subject

[1] Schattenfroh, Archiv f. Hygiene, 1900, 38, p. 108.

is resting quietly in a respiration chamber with a relative humidity inside the chamber not far from 50 per cent. Under these conditions 35 per cent of the total water vaporized is computed as having been vaporized from the lungs.

TABLE 57.—*Proportions of total water vaporized from the lungs and skin, respectively, during sleep after rest.*

Subject.	Proportion of water vaporized.		Subject.	Proportion of water vaporized.		Subject.	Proportion of water vaporized.	
	From lungs.	From skin.		From lungs.	From skin.		From lungs.	From skin.
	P. ct.	*P. ct.*		*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*
W. O. A....	29.8	70.2	B. F. D....	27.2	72.8	H. E. S.....	37.0	63.0
D. W.	47.6	52.4	C. R. Y.....	24.0	76.0	H. L. K....	33.9	66.1
H. C. K....	38.6	61.4	H. A.	28.6	71.4			
H. F.	35.0	65.0	A. H. M....	37.6	62.4	Average	34.7	65.3
A. L. L....	31.0	69.0	H. R. D....	38.4	61.6			
N. M. P....	39.4	60.6	S. A. B.....	38.1	61.9			

RATIO OF WATER VAPORIZED DURING SLEEP TO WATER VAPORIZED DURING WAKING HOURS.

The general state of lowered metabolism obtaining during sleep would be expected to have an effect upon the vaporization of water, consequently it is of importance to compare the water vaporized during sleep with that vaporized during the waking hours. The average results for 17 subjects have been collected in table 58, in which are shown the water vaporized per hour during sleep and the water vaporized per hour during the waking hours.

TABLE 58.—*Ratio of water vaporized during sleep to that vaporized during waking hours in rest experiments.*

Subject.	(*a*) Amount per hour during sleep.	(*b*) Amount per hour during waking hours.	(*c*) Ratio sleeping to awake. $(b+a)$	Subject.	(*a*) Amount per hour during sleep.	(*b*) Amount per hour during waking hours.	(*c*) Ratio sleeping to awake. $(b+a)$
	Grams.	*Grams.*			*Grams.*	*Grams.*	
W. O. A.....	34.9	36.3	100:104	C. R. Y.......	44.5	38.0	100: 85
D. W.	27.7	36.2	131	J. F. S........	30.9	35.6	115
J. C. W.....	36.2	36.7	101	A. H. M.......	25.4	29.0	114
H. C. K.....	30.3	35.4	117	H. R. D.......	25.1	25.7	102
H. F.	30.9	29.7	96	S. A. B........	26.9	26.7	99
A. L. L.....	35.4	34.9	99	H. E. S........	29.2	27.3	93
A. W. S.....	33.5	35.7	107	H. L. K.......	28.6	34.9	122
E. O.	38.1	36.5	96				
N. M. P.....	29.9	38.2	128	Average ..	32.1	34.2	100: 107
B. F. D.....	38.9	44.8	115				

In this series of experiments, in which the muscular conditions were practically the same, *i. e.,* no external muscular work, the water vaporized during the waking hours when the subject was quietly sitting reading or writing was on the average slightly greater than that vaporized when the same subject was lying asleep, with light covering, the ratio of the amount vaporized during sleep to that during the waking hours being on the average as 100:107. It could be noted, however, that with 6 out of the 17 subjects the water vaporized during waking hours was actually less than during the night.

The majority of experiments on the quantitative relations of the amounts of water vaporized from the lungs and skin of man have been made either for the purpose of studying general problems of hygiene (like those of Sondén, Tigerstedt and Rubner), problems which could well be solved by researches with only an approximate degree of accuracy, or the water determinations were made for the evidence they presented as to the energy required to vaporize the water (as in the experiments made by Atwater and his associates). It is clear from the foregoing consideration that researches are needed for the study of the water-vapor elimination *per se*. Such researches should be taken into consideration, the respiration from the lungs and skin each studied separately, and the many factors influencing such transpiration, as body-temperature, especially during pyrexia, muscular activity, clothing, movement of the air, external temperature, and variations in the rate of circulation of the blood.

CARBON-DIOXIDE ELIMINATION.

EARLIER INVESTIGATIONS.

The close relationship between the combustion of fuel and the production of carbon dioxide on the one hand, and vital activity and the exhalation of carbon dioxide on the other, early led to a careful study of this product of respiration. Fortunately, the determination of the proportion of carbon dioxide in the expired air presents no special difficulty, since the methods for determining carbon dioxide, either volumetric or gravimetric, are exceedingly accurate. It is somewhat difficult, however, to determine quantitatively the carbon dioxide exhaled from the human body in the course of an experimental period, as this usually involves a knowledge of the volume of the total air expired, and the methods for measuring the total air expired during an experimental period have not been perfected and are still open to criticism.

The earlier attempts to determine the total 24-hour output of carbon dioxide have been discussed in detail by other writers,[1] and it is unnecessary here to go into a lengthy historical account of the methods employed. Many of the earlier results are of general interest when viewed in the light of results obtained by modern methods, and hence it is fitting that such of the earlier work as possesses a distinct physiological as distinguished from an historical interest should here be reviewed.

The early observations of Lavoisier and Seguin have an unusual interest, since the estimation of the oxygen required by resting man as made by them coincides with wonderful accuracy with determinations made by the best methods of the present day. The carbon-dioxide determinations reported by these investigators, however, fluctuate widely. In the memoir[2] of 1789 they state that

[1] Zuntz, Hermann's Handbuch der Physiologie, 1882, 4, 44, p. 118.

[2] Lavoisier and Seguin, Premier Memoire sur la Respiration des Animaux. Histoire de l'Academie des Sciences, Paris, 1789, pp. 566–584.

the carbon dioxide formed in 24 hours[1] was approximately 1200 grams. In the memoir of 1790[2] they report that the total carbon-dioxide excretion amounted to approximately 600 grams.[1]

The conditions under which the experiments were made are described in only too meager a manner by these writers, and we have absolutely no knowledge regarding the kind of apparatus used in the experimenting other than the idea given by 2 excellent drawings ascribed to Madame Lavoisier,[3] and consequently we can judge but little of the true value of these data.

One of the earliest methods for studying the carbon-dioxide output was to exhale the gas from the lungs into a rubber bag during a specified length of time and subsequently to analyze the air. This method was used in 1839 by Coathupe.[4] The bag, which contained 130 cubic inches, was filled by successive expirations, great care being taken to prevent the inspiration by the subject of any air which he had once breathed. A sample of the air was passed into a special tube with stopcocks at each end, and the carbon dioxide was absorbed in limewater. Coathupe calculated that in 24 hours there were 5.45 ounces avoirdupois of carbon exhaled. This corresponds to 154.5 grams of carbon, which are equivalent to 566.6 grams of carbon dioxide in 24 hours.

TABLE 59.—*Carbon-dioxide elimination of subjects in experiments reported by Andral and Gavarret.*

Age.	Carbon dioxide per hour.	Muscular condition.	Age.	Carbon dioxide per hour.	Muscular condition.
Men.	*Grams.*		*Men.*	*Grams.*	
16.5 years...	37.4	Well developed.	37 years.....	39.2	Fair.
17 years.....	37.4	Do.	40 years.....	44.4	Very well developed.
18 years.....	40.7	Do.	41 years.....	38.1	Fair.
19 years.....	41.1	Do.	45 years.....	31.5	Very tall and thin.
20 years.....	41.1	Do.	48 years.....	38.5	Well developed.
24 years.....	40.7	Fair.	50 years.....	39.2	Do.
24 years.....	42.5	Do.	51 years.....	37.0	Fair.
26 years.....	51.7	Extra well developed.	54 years.....	38.9	Very well developed.
26 years.....	40.3	Fair.	59 years.....	36.7	Fair.
27 years.....	43.3	Well developed.	60 years.....	49.9	Extra well developed.
28 years.....	45.5	Do.	*Women.*		
31 years.....	40.7	Do.	19 years.....	25.7	Very well developed.
32 years.....	42.2	Do.	22 years.....	24.6	Well developed.
33 years.....	39.2	Fair.	26 years.....	22.0	Slight.

An extended series of experiments was made in 1843 by Andral and Gavarret,[5] who studied the carbon-dioxide excretion of a relatively large number of different individuals. Their method involved the use of a face-mask which permitted breathing either through the mouth or through the nose, and the air was aspirated through this mask which was connected with 3 large glass globes from which the air had previously been exhausted. The expired air

[1] Estimated from the old French weights as given in the memoir.
[2] Lavoisier and Seguin, Histoire de l'Academie des Sciences, Paris, 1790, pp. 608-610.
[3] Grimaux, Lavoisier 1743-1794, Paris, 1899, pp. 119 and 129.
[4] Coathupe, Philosophical Magazine, 1839, 3d ser., 14, p. 401.
[5] Andral and Gavarret, Ann. de Chim. et de Phys., 1843, ser. 3, 8, p. 129.

drawn into these globes was subsequently analyzed, and from the analyses and the volume of air the carbon-dioxide production was calculated. Unfortunately, these writers did not give the body-weights of their subjects and these data will be greatly missed, as may be seen later in this discussion, since the carbon-dioxide production varies in general with the body-weight. The results as presented by these investigators have been computed on the basis of the number of grams of carbon dioxide per hour and reported elsewhere.[1] A portion of the table given by Sondén and Tigerstedt is reproduced herewith (table 59).

Using a respiration chamber containing about 1000 liters, Scharling[2] studied the carbon-dioxide exhalation of a number of individuals. He confined himself to experiments of 35 to 45 minutes' duration, as he feared the possible influence upon the respiratory exchange of an increase in the percentage of carbon dioxide in the air. The results have been calculated on the basis of carbon-dioxide excretion per hour by Sondén and Tigerstedt, and certain of the results, comparable with the experiments made in the Wesleyan University chamber, are given in table 60.

TABLE 60.—*Carbon-dioxide elimination of subjects in experiments reported by Scharling.*

Subject.	Age.	Body-weight.	Carbon dioxide per hour.
	Years.	*Kilos.*	*Grams.*
Man	35	66	33.8
Man	28	82	36.7
Boy	16	58	34.3
Girl	19	56	25.3

In connection with the researches of Scharling, it should be pointed out that the criticism raised by Zuntz that Scharling's method probably gave too low results should be borne in mind. Scharling himself noted a turbidity in lime-water held at the opening of his air-pump.[3]

Valentin and Brunner[4] breathed for 15 minutes through a flask and then analyzed its contents. In other experiments they collected the total expired air in a gasometer. In his experiments on himself, Valentin, who was 33 years old, exhaled with a somewhat rapid respiration 42 grams of carbon dioxide per hour. The average of all experiments on both Valentin and Brunner, 6 in number, showed a carbon-dioxide output of 41 grams per hour. The authors point out that this agrees with the results obtained by Andral and Gavarret, but they also point out that owing to the increased respiration the results are somewhat too high for ordinary quiet daily respiration.

By collecting the expired air in a glass bell-jar over a salt solution and subsequently analyzing it, Vierordt[5] determined the total carbon-dioxide output

[1] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, 6, pp. 55 and 56.
[2] Scharling, Ann. der Chem. u. Pharm., 1843, 45, p. 214.
[3] Zuntz, Hermann's Handbuch der Physiologie, 1882, 4, p. 123.
[4] Valentin and Brunner, Lehrbuch der Physiologie des Menschen, 1841, 1, p. 565.
[5] Vierordt, Physiologie des Menschen, Heidelberg, 1845.

of man. It was necessary in his apparatus to inhale through the nose, and to expire through the lips with a mouthpiece. The results of the various experiments showed remarkable uniformity. The carbon dioxide expired from the lips, reduced to 0° and 760 mm., varied from 201 c. c. to 256 c. c., the average being 232 c. c. per minute.

Using the apparatus of Scharling, Hannover[1] made a large number of experiments with patients, particularly those affected with lung diseases. Four experiments were made on healthy individuals. The experiments usually lasted an hour and were made between 10 a. m. and 1 p. m. The results, computed on the basis of carbon dioxide per hour, are given in table 61.

TABLE 61.—*Carbon-dioxide elimination of subjects in experiments reported by Hannover.*

Subject.	Age.	Body-weight.	Carbon dioxide per hour.	Carbon dioxide per kilo of body-weight per hour.
	Years.	*Kilos.*	*Grams.*	*Gram.*
Man	16	57.8	34.21	0.592
Man	28	82.0	36.63	.447
Man	35	65.5	33.51	.512
Woman	19	55.8	25.15	.451

In these experiments, as in those of Scharling's, the subject was confined inside of a respiration chamber and in all probability was very quiet.

A most extended series of observations, some of them of long duration, was made on himself by Edward Smith.[2] His apparatus is characterized as being the first apparatus with a mouthpiece or mask in which the total carbon dioxide was absorbed and weighed. In this case the air was passed through a specially constructed box containing potash which absorbed all the carbon dioxide, the moisture exhaled into the air being collected over sulphuric acid and the increase in weight in the vessels being noted on a sensitive balance. A considerable number of experiments were made on 4 different subjects. The results are expressed in English grains, and Sondén and Tigerstedt have calculated the results on the gram basis and reported them in considerable detail in their report.[3] The author made a large number of experiments, studying the effect of different foods and stimulants upon respiration; the time of day was likewise noted and some observations were made during sleep or during drowsiness. In one experiment, Smith breathed almost uninterruptedly through the mask for about 18 hours, removing it only during meals.

From the results obtained for the 18 hours while awake, the author computed the results for periods when the subject was asleep, and concludes that the carbon dioxide excreted by the 4 subjects used in his experiments would

[1] Hannover, De quantitate relativa de absoluta acidi carbonici ab homine sano et aegroto exhalati, Hauniae, 1845.
[2] Smith, Philosophical Transactions, 1859, **149**, p. 681.
[3] Sondén and Tigerstedt, Skand. Archiv f. Physiol, 1895, **6**, p. 101.

be for 24 hours of rest with the average amount of sleep, 6.735 ounces of carbon (700.1 grams carbon dioxide), 7.845 ounces (815.5 grams carbon dioxide), 5.6 ounces (582.1 grams carbon dioxide), and 6.54 ounces (679.8 grams carbon dioxide) with the 4 subjects, respectively.

Using the great Pettenkofer respiration chamber in Munich, Ranke[1] determined the carbon-dioxide output of a man at rest, both with and without food (table 62). The body-weight of the subject varied somewhat with the time of year.

TABLE 62.—*Carbon-dioxide elimination of subject in experiments reported by Ranke.*

Weight.	Food.	Carbon dioxide in 24 hours.
Kilos.		*Grams.*
72.68	Unknown diet	791.1
73.85	Regular diet	759.5
72.87	Fasting	662.9
71.79	....Do.	663.5
72.57	Diet without protein	735.2
72.85	1832 grams of meat	847.5
74.22	Very large diet	925.6

Using the same apparatus, Pettenkofer and Voit report in their memoir[2] the results of a number of experiments with men at rest inside the chamber. The results are as follows:

Two experiments were made on fasting subjects, during which time the subject gave off 738 and 695 grams of carbon dioxide in 24 hours. Three experiments were made with an average diet, during which time the total carbon-dioxide exhalation was 912, 943, and 930 grams, respectively. Two were made with a high-protein diet, during which time the carbon-dioxide excretion was 1003 and 1038 grams, respectively, and one with a protein-free diet in which 839 grams of carbon dioxide were exhaled in 24 hours. In a second experiment with a protein-free diet, 522 grams of carbon dioxide were exhaled in the 12 hours of the day, as compared with 508 grams in the preceding experiment in the same period of time and under like dietetic conditions. When the same diet was given morning and night, the total carbon-dioxide excretion was 932 grams. With another subject on an ordinary diet, the total exhalation of carbon dioxide was 695 grams in 24 hours. In one experiment without food, which continued only during the 12 hours of the night, the carbon-dioxide excretion was 360 grams.

Working in Voit's laboratory, Lossen[3] used an apparatus for studying the carbon-dioxide excretion with voluntary alterations of the depth and rapidity of respiration. In this research, while the technique in the experiments with the higher respiration-rate and deeper respirations are open to criticism, the results with the ordinary respiration-rate (for this subject 15 per minute) are

[1] Ranke, Archiv f. Anat., Physiol. u. wiss. Med., 1862, p. 311.
[2] Pettenkofer and Voit, Zeitschr. f. Biol., 1866, 2, p. 546.
[3] Lossen, Zeitschr. f. Biol., 1866, 2, p. 244.

probably not far from correct, and from the data obtained at this rate of respiration, Lossen computes that he exhaled 703 grams of carbon dioxide in 24 hours. He points out that this agrees satisfactorily with the values found by Ranke, with an average of 760 grams per 24 hours.

Dissatisfied with the technique of Lossen's experiments, particularly under conditions with a high rate of ventilation of the lungs, Berg[1] repeated Lossen's experiment with identically the same apparatus, taking certain precautions. The author computes his daily carbon-dioxide elimination as but 600 grams, and compares this with the 760 grams obtained by Ranke, 703 grams by Lossen, 800 grams by Scharling, and 743 grams by Edward Smith. The author himself points out, however, that he does not consider his results physiological, as the apparatus used certainly retards respiration.

Leibermeister[2] used a respiration chamber somewhat after the Scharling type and determined the carbon-dioxide elimination of 2 men. The first subject was a carpenter, 19 years of age, 165.5 cm. high and weighing 53.5 kilos. The carbon-dioxide elimination for successive one-half-hour periods was 16.4, 16.3, 16.9, and 15.9 grams, respectively, averaging 16.4 grams. Five days later the same subject, in four consecutive half-hour periods, exhaled 16.9, 16.4, 16.9, and 16.7 grams, respectively, the average for the second experiment being 16.7 grams. A second series of experiments was carried out on a man 42 years of age, 177 cm. high, and weighing 68.5 kilos. In 2 experiments, he exhaled, while lying down and quiet, 15.6 and 14.7 grams of carbon dioxide per half hour. When sleeping heavily he exhaled 12.3 grams in the first experiment, and in the second experiment, with two different periods, 12.7 and 12.3 grams, respectively.

By means of a method involving the use of a mouthpiece and spirometer, Speck[3] made a very large number of experiments upon himself, studying the respiratory exchange in short periods. He also made a number of experiments on other subjects, the results of which have been computed on the basis of the carbon-dioxide elimination per hour, and per hour per kilogram of body-weight. Such results as are comparable with the experiments reported in this publication are given in table 63.

TABLE 63.—*Carbon-dioxide elimination of subjects in experiments reported by Speck.*

Subject.	Age.	Body-weight.	Carbon dioxide per hour.	Volume per minute.	Carbon dioxide per hour and per kilo.
		Kilos.	*Grams.*	*c.c.*	*Gram.*
Girl	20	47	22.6	192	0.481
Girl	17	52	27.0	229	.519
Boy	17	55	30.9	262	.562
Woman	24	58	23.3	198	.403
Man	50	62	27.6	234	.445
Man	31	72	31.5	267	.438
Man	57	62	25.5	216	.411

[1] Berg, Deutsch. Archiv f. klin. Med., 1869, 6, p. 291.
[2] Leibermeister, Deutsch. Archiv f. klin. Med., 1870, 7, p. 75.
[3] Speck, Physiologie des Athmens, Leipzig, 1892, p. 209.

From over 80 experiments on himself, Speck collected a number that he considered truly representative of his normal metabolism in the morning without food, and from these results he concluded that on the average he excreted 234 c. c. of carbon dioxide per minute.

Using the Pettenkofer respiration apparatus in Munich, Möller[1] made experiments with a number of hospital patients and 3 healthy individuals. Of these, a man, 44 years of age, weighing 68.8 kilos, exhaled 33.5 grams of carbon dioxide per hour, or 284 c. c. per minute and 4.14 c. c. per kilogram per minute. Another subject, 36 years of age, weighing 52.5 kilos, exhaled 33 grams per hour, or 280 c. c. per minute and 5.32 c. c. per kilogram per minute. A third subject, 28 years of age, with a body-weight of 70 kilos, gave off 44.3 grams of carbon dioxide per hour, or 376 c. c. of carbon dioxide per minute and 5.38 c. c. per kilogram per minute.

In 1888[2] there appeared a description of a new method for studying the respiratory exchange which was destined to revolutionize the study of metabolism during short periods—the method of Zuntz-Geppert—which has, in the hands of Magnus-Levy, Loewy, and many others of the Zuntz school, yielded a large number of results. The subject breathes through a mouthpiece into a carefully calibrated gas-meter, and an aliquot portion of the air is taken for analysis in duplicate by exact methods. It is impossible in this abstract to include all the results obtained by the many workers with this method. Those most comparable with the results here reported are such as were obtained on men lying quietly, 12 hours after the last meal. The method has been used extensively for studying the influence of various factors upon the respiratory exchange and almost invariably each research has included a certain number of experiments on the resting value without food, as a basis for comparison in studying the different factors. It is still a matter of conjecture as to how accurate are the results with this method when the subjects are not trained in the peculiar respiration necessitated by using the rubber mouthpiece and nose-clamp. In all probability the results obtained by Zuntz and his co-workers on themselves have a high degree of accuracy. The results obtained on others are open to reasonable criticism. Fortunately, most of the work, and that most carefully carried out, was done on the subjects trained in the Zuntz school. Magnus-Levy[3] used the method especially for studying the influence of the ingestion of food upon the respiratory exchange.

The most recent collection of the results obtained by this important method is given by Loewy.[4] The results, not only for the carbon-dioxide exhalation but likewise for the oxygen consumption and the respiratory quotient, are given in table 64, which is copied directly from Loewy's article. The larger number of

[1] Möller, Zeitschr. f. Biol, 1878, **14**, p. 542.
[2] Zuntz and Geppert, Archiv f. d. ges. Physiol., 1888, **42**, p. 196.
[3] Magnus-Levy, Archiv f. d. ges. Physiol., 1894, **55**, p. 1.
[4] Loewy, Oppenheimer's Handbuch der Biochemie des Menschen und der Tiere, Jena, 1908, **4**, p. 179.

results are taken from the extensive article by Magnus-Levy and Falk.[1] In addition to the data in the original table, we have for purposes of comparison computed the results on the basis of per square meter of body-surface per minute.

TABLE 64.—*Gas exchange per minute by adults, as determined with the Zuntz-Geppert apparatus.*

No.	Age.	Body-weight.	Per person and per minute.		Per kilo body-weight and per minute.		Respiratory quotient.	Per square meter of body-surface per minute.	
			Oxygen consumed.	Carbon dioxide exhaled.	Oxygen consumed.	Carbon dioxide formed.		Oxygen consumed.	Carbon dioxide formed.
	Years.	*Kilos.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*		*c. c.*	*c. c.*
1	24	43.2	195.8	146.9	4.53	3.40	0.750	128.8	96.6
2	24	48.0	176.8	156.4	3.68	2.88	0.783	108.5	96.0
3	30	50.8	189.4	156.5	3.73	3.08	0.826	112.1	92.6
4	36	53.0	219.5	168.2	4.14	3.45	0.833	126.2	96.7
5	24	56.3	248.3	180.9	4.41	3.21	0.728	137.2	99.9
6	56	56.5	222.0	188.0	3.93	2.98	0.766	122.7	103.9
7	32	58.0	221.2	162.5	3.81	2.90	0.760	120.2	88.3
8	—	58.5	231.8	173.4	3.96	3.05	0.770	124.6	95.9
9	38	60.0	227.0	177.7	3.80	2.96	0.779	120.1	94.0
10	—	61.2	336.4	254.5	5.50	4.18	0.760	176.1	133.2
11	43	65.0	220.6	162.5	3.39	2.50	0.740	110.9	81.7
12	—	66.1	226.0	172.2	3.42	2.60	0.760	112.4	85.7
13	25	67.5	231.3	192.5	3.43	2.86	0.830	113.4	94.4
14	22	67.5	231.3	200.2	3.43	2.97	0.865	113.4	98.1
15	23	71.7	267.5	212.4	3.73	2.96	0.793	126.2	100.2
16	34	73.6	248.2	196.1	3.37	2.66	0.789	114.9	90.8
17	34	82.0	226.3	178.3	2.76	2.17	0.788	97.5	76.9
18	29	82.7	297.6	225.4	3.60	2.72	0.757	127.2	96.3
19	22	88.3	291.7	237.4	3.30	2.69	0.814	119.5	97.3
Average			237.3	181.4	3.79	2.96	0.781	121.7	95.7

Hanriot and Richet[2] made a number of experiments on resting man, employing a new method for determining the respiratory exchange which involved the use of 3 gas-meters for measuring, first, the volume of the air inspired; second, the volume of the air expired; and third, the volume of the air expired after absorbing the carbon dioxide. As a result of their experiments, they conclude that an adult man in a state of fasting produces per kilogram of body-weight per hour 0.5 gram of carbon dioxide, or 4.24 c. c. per kilogram per minute, and absorbs 0.45 gram of oxygen per kilogram of body-weight per hour, or 5.25 c. c. per kilogram per minute. During digestion, there is 0.6 gram of carbon dioxide per kilogram of body-weight per hour, or 5.09 c. c. per kilogram per minute, and 0.5 gram of oxygen per kilogram per hour, or 5.84 c. c. per kilogram per minute.

Using the little-known Pashutin respiration apparatus in St. Petersburg, Sadovyen[3] in 1888 made a number of experiments on healthy man in which the carbon-dioxide production was determined for the greater part of 24 hours. On one day with food, the output of carbon dioxide of a man weighing 79 kilos was 946 grams, when calculated to the basis of 24 hours. In a 2-day

[1] Magnus-Levy and Falk, Archiv f. Anat. u. Physiol., Physiol. Abth., Supp. Bd., 1899, p. 314.

[2] Hanriot and Richet, Compt. rend., 1888, 106, p. 496.

[3] Sadovyen, Publications of the Russian Society of General Hygiene, St. Petersburg, 1887-1888, 12, p. 13.

fasting experiment, he found 755 and 746 grams of carbon dioxide, respectively. Another day following with food showed an output of 1098 grams of carbon dioxide. In a 4-day fasting experiment he found carbon dioxide on the successive days amounting to 810, 795, 620, and 613 grams, respectively. In 1 day with food following fast, 846 grams were found, and on 3 other days, when large amounts of starch and sugar were given, he found 970, 1058, and 899 grams of carbon dioxide, respectively. The body-weight of the subject varied from 75 to 80 kilos.

A few years later, Likhatscheff,[1] using the same apparatus, made a series of experiments, 6 in all, on 2 subjects. The carbon-dioxide production for 24 hours with 1 subject, 24 years of age, and weighing 57 kilos, was 596 grams on a fasting day, and 729 and 700 grams on days with ordinary diet, and 827 grams on a day with a very large diet. During this day likewise the subject was much more muscularly active, as he was weighed every 2 hours during the day and every 4 hours during the night, thus accounting for the larger carbon-dioxide excretion. With a second subject, who was likewise 24 years of age, but who weighed 66 kilos, 2 days with ordinary diet showed a carbon-dioxide production amounting to 867 grams and 831 grams, respectively. In an experiment with a woman patient, 17 years (50 kilos), and having malarial fever, Likhatscheff and Avroroff,[2] making observations on the day "without fever," found that the carbon-dioxide excretion averaged for 22 hours 23.3 grams per hour. The minimum was from 1 a. m. to 3 a. m., 18 grams per hour, and the maximum was 26.5 grams per hour between 7 p. m. and 11 p. m., at the beginning of the experiment. For the greater part of the time when awake, the subject exhaled with considerable regularity an average of 25 grams per hour. When asleep this fell on the average to somewhat less than 20 grams per hour.

Laves,[3] using the Hoppe-Seyler respiration apparatus for man, made 7 experiments on a healthy man weighing about 66 kilos, and found the carbon-dioxide excretion computed on the 24-hour basis to be 719.8, 599.1, 625.2, 587.3, 673.7, 675.7, 581.4 grams, respectively. The author makes no comments on the lack of agreement in these results, and the only information with regard to the diet is the statement that in the second and third experiments, the proportion of bread in the ration as compared with that of meat was somewhat increased.

Schnyder,[4] using the apparatus in Kronecker's laboratory, in which the total amount of carbon dioxide was absorbed by soda-lime, found with a healthy quarryman, 22 years of age and weighing about 64 kilos, that in 2 experiments, 1 month apart, he excreted at the rate of 54 and 53 grams per hour, respectively, while standing quietly in the laboratory.

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[1] Likhatscheff, Production of heat by healthy man in the condition of comparative rest. Dissertation (Russian), St. Petersburg, 1893.

[2] Likhatscheff and Avroroff, Reports of the Imperial Military Medical Academy, St. Petersburg, 1902, 5.

[3] Laves, Zeitschr. f. physiol. Chemie, 1894, 19, p. 590.

[4] Schnyder, Zeitschr. f. Biol., 1896, 33, p. 289.

In the experiments of Gruber[1] the carbon dioxide from the total expired air was absorbed in soda-lime. An experiment made on himself when he was 25 years of age and weighed 69 kilos showed that while at rest (sitting in a chair) he exhaled carbon dioxide at the rate of 29.12 grams per hour. The total carbon dioxide in 2 other experiments was 38.25 and 38.75 grams per hour. In the first experiment the subject had had a cup of coffee with a small piece of bread 4 hours before; the other 2 experiments were made 5 hours after a heavy meal, but the author states that in the first of these 2 experiments there may have been a leak.

With the desire to study the normal production of carbon dioxide of men and women of different ages, Sondén and Tigerstedt[2] carried out an heroic investigation on the carbon-dioxide production of different individuals. They used for this purpose a large respiration chamber, designed and built by them in Stockholm. The experiments were planned to study the total respiration products, particularly the simultaneous carbon-dioxide production of a number of persons. To this end, from 6 to 10 people were confined in the respiration chamber at the same time for experiments lasting from 2 to 8 hours, and a number of experiments were also made on individuals, which extended over the greater part of the 24 hours. The subjects included men and women of all ages, from children to elderly people. Such results as are more or less comparable with the experiments here reported are given in table 65.

TABLE 65.—*Carbon-dioxide elimination of subjects in experiments reported by Sondén and Tigerstedt.*

Average age of the group studied.	Average body-weight.	Carbon dioxide production per person and per hour.
Years.	*Kilos.*	*Grams.*
19.51	59.5	42.7
22.93	65.3	37.8
25.00	67.5	38.4
34.72	68.3	35.3
44.39	76.5	36.7
57.57	84.6	34.4

With a group of women having an average age of 17.69 years and a body-weight of 53.9 kilos, they obtained 27.1 grams of carbon dioxide per hour. Another group, with an average age of about 30 years, and a weight of 53.9 kilos, exhaled 29.1 grams of carbon dioxide per hour.

Another series of experiments was made by Sondén and Tigerstedt on different individuals during the greater part of the 24 hours, and these, together with the earlier experiments made by these writers, will be frequently referred to in a subsequent discussion.

[1] Gruber, Zeitschr. f. Biol., 1891, 28, p. 472.
[2] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, 6, p. 1.

Recently Johansson[1] studied a series of 10 young men and 2 women, determining the carbon-dioxide production in the Stockholm chamber 12 hours after the last meal with unusual muscular rest. The results which are given in table 66 herewith have an especial interest here, since the experiments were made with subjects of the same age and body-weight as many of those studied by us.

TABLE 66.—*Carbon-dioxide elimination of subjects in experiments reported by Johansson.*

Subject.	Age.	Body-weight.	Height.	Carbon dioxide per hour.
Men.		*Kilos.*	*cm.*	*Grams.*
S—st	22	61	180	22.2
L—hl	21	58	172	22.3
E—d	22	57	171	20.1
L—m	21	85	178	25.6
W—d	23	73	178	21.9
E—n	22	71	182	24.5
B—g	27	87	181	25.3
N—d	22	74	168	26.1
F—st	26	86	181	26.7
R—n	21	65	167	20.0
Women.				
S—f	26	54	163	16.7
M—l	24	60	167	19.1

During the past decade a number of researches have been carried out in the Hygienic Institute in Berlin under Rubner's direction. The most important of these for purposes of comparison in this report are as follows:

In a number of experiments on a well-nourished subject weighing 71 kilos, at a temperature of 17.4° C., the average carbon-dioxide production was 32.1 grams per hour.[2]

With another subject, H., weighing 58 kilos and well nourished, the carbon-dioxide production at 20° to 23° C. averaged 29 grams per hour.[3]

Wolpert, working in Rubner's laboratory, found with a subject weighing 58 kilos, at a temperature of 15° to 25° C., an average of 24.6 grams of carbon dioxide per hour.

Laschtschenko,[4] also working in Rubner's laboratory, found with a subject weighing 70 kilos that the hourly carbon-dioxide production at 17° to 19° C. in 6 experiments was 27.69, 23.84, 26.64, 26.68, 23.32, and 23.83 grams, respectively.

Another of Rubner's pupils, Schattenfroh,[5] studying a very fat man weighing 95 kilos and 53 years old, found that at 20° C. the carbon-dioxide production varied from 26.7 to 34.5 grams per hour in 4 experiments.

[1] Johansson, Skand. Archiv f. Physiol., 1908, **21**, p. 1.
[2] Rubner, Archiv f. Hygiene, 1900, **38**, p. 133; *ibid.*, Die Gesetze des Energieverbrauchs bei der Ernährung, Leipsic and Vienna, 1902, p. 203.
[3] Rubner, Archiv f. Hygiene, 1897, **29**, p. 33.
[4] Laschtschenko, Archiv f. Hygiene, 1898, **33**, p. 148.
[5] Schattenfroh, *ibid.*, 1900, **38**, p. 108.

Wolpert[1] obtained a carbon-dioxide production of a resting man of 25.99, 26.89, 27.97, and 28.04 grams, respectively, per hour. These values were calculated upon a body-weight basis of 70 kilos. Wolpert[2] continued his experiments on other individuals at rest, and an average of 3 experiments on a seamstress with a body-weight of 44 kilos showed an excretion of 22.81 grams of carbon dioxide per hour; with a writer (64 kilos) 2 experiments gave an average of 32.32 grams per hour; with a tailor (49 kilos) 2 experiments gave an average of 26.09 grams; with a lithographer (64 kilos) 2 experiments showed 32.32 grams; and with a woman shoe-machine operator (44 kilos) 3 experiments showed an average of 22.81 grams; with a draughtsman, body-weight 64 kilos, 2 experiments showed an average of 32.32 grams; with a mechanic, body-weight 43 kilos, 2 experiments gave an average of 31.41 grams; with a woman shoemaker, body-weight 62 kilos, the average of 2 experiments was 31.49 grams; a man shoemaker, body-weight 47 kilos, gave an average of 29.73 grams from 2 experiments.

In 1904, Jaquet[3] described a new type of respiration apparatus in which he determined not only the carbon dioxide produced, but likewise the oxygen absorbed. In an experiment which lasted 11 hours, the carbon-dioxide production of the subject, who was 32 years of age and weighed 59.5 kilos, varied from 37 grams to 28.2 grams per hour.

Staehelin,[4] using the same apparatus, reports a number of experiments on himself during the night, and the amounts per hour calculated on the basis of 12 hours are given on page 165 of this report.

With the primary object of studying the gas exchange in pathological cases, Grafe[5] has devised a respiration apparatus consisting of a helmet, and the analyses of the air passing through it are made according to the Jaquet method. The author states, as a result of a number of experiments on healthy men, that he finds the average carbon-dioxide production to equal 3.12 c. c. per minute and per kilogram of body-weight. The value is likewise given for oxygen as 4.04 c. c. The author points out that these values correspond to those given by Magnus-Levy and others working with the Zuntz-Geppert apparatus.

The earliest reports of the experiments made with the respiration apparatus in the chemical laboratory of Wesleyan University, Middletown, Connecticut, were published in 1897.[6] The results of these earlier experiments, as well as those made subsequently, are included in the tables, consequently it will be unnecessary to mention them further here.

Conclusions regarding earlier investigations.—An examination of the results obtained by different writers in the early literature shows two things: (1) that

[1] Wolpert, *ibid.*, 1896, **26**, p. 32.
[2] Wolpert, *ibid.*, **26**, p. 68.
[3] Jaquet, Verhandl. Naturf. Gesellsch. Basel, 1904, **15**, p. 252.
[4] Staehelin, Zeitschr. f. klin. Med., 1906, **66**, p. 201.
[5] Grafe, Deutsch. Archiv f. klin. Med., 1909, **95**, p. 529.
[6] Atwater, Woods, and Benedict, U. S. Dept. Agr., Office Expt. Stas. Bul. 44, 1897.

as years progressed, the technique rapidly improved until finally at the present time we have a number of excellent methods for determining the carbon-dioxide production; (2) the influence of a number of factors on respiratory exchange is distinctly shown and consequently, to make experiments strictly comparable, it is necessary that the experiments be made at given hours of the day and with due regard to diet, muscular activity, and the size of the subject.

The earlier experiments were almost invariably made with the express purpose of studying the respiratory exchange as affected by some particular factor. Aside from the experiments of Sondén and Tigerstedt,[1] and Magnus-Levy and Falk,[2] few researches have been made on the normal carbon-dioxide output of resting man, and hence the results here collected represent the largest number of experiments on different individuals made by modern methods that has as yet appeared.

EXPERIMENTS ON CARBON-DIOXIDE ELIMINATION.

The carbon-dioxide elimination of man during fasting has been discussed at considerable length in a previous publication,[3] and especial stress is laid only upon those among the earlier experiments that are strictly comparable with those here reported. It is obvious that the ingestion of food, and muscular exercise both play an important rôle in the excretion of carbon dioxide. It is the purpose of this report to discuss in more detail the factors influencing the carbon-dioxide production, and since it was found with the water elimination that the more constant conditions for comparison were obtained during sleep, *i. e.*, when no food was taken and when the muscular activity was relatively constant, the carbon-dioxide production of men during sleeping hours is first considered. Fortunately, a large number of experiments were made in which the carbon-dioxide production during sleep was determined with considerable accuracy.

Since it is obvious from the earlier literature that the body-weight of the subject plays an important rôle in the total carbon-dioxide excretion, in presenting the material regarding the carbon-dioxide excretion herewith, it has been deemed advisable to give not simply the amount per hour but likewise the amount per kilogram of body-weight per hour and per square meter of body-surface per hour. Many of the earlier writers have computed their results upon the basis of volume of carbon dioxide expired, and consequently our results are also presented on the basis of cubic centimeters per minute, per kilogram of body-weight per minute, and per square meter of body-surface per minute.

CARBON-DIOXIDE ELIMINATION DURING SLEEP.

The values given in table 67 are the average values obtained in observations from 1 a. m. to 7 a. m., with different individuals. With one individual only 1 experiment was made, with others as many as 20; but as during the

[1] Sondén and Tigerstedt, *loc. cit.*
[2] Magnus-Levy and Falk, *loc. cit.*
[3] Benedict, Carnegie Institution of Washington Publication No. 77, 1907.

hours, 1 a. m. to 7 a. m., there is the minimum muscular exertion, and food had not been taken for several hours previously, there is no reason for believing that the results are not truly representative of the normal carbon-dioxide production of these individuals under the conditions obtaining inside the respiration chamber. The subjects were cautioned not to move or uncover the body before 7 a. m. even if, as occasionally happened, they awoke before that hour. For convenience, the experiments are arranged in the order of the body-weights of the subjects. The amounts of carbon dioxide excreted per hour vary from 19.4 grams to 27.5 grams. The average amount for 19 subjects during the period from 1 a. m. to 7 a. m. is 23.4 grams per hour.

TABLE 67.—*Carbon dioxide eliminated during sleep by different individuals, 1 a. m. to 7 a. m.*

Subject.	Body-weight (without clothing).	Height.	Amount per hour.	Amount per minute.	Per kilogram of body-weight.		Per square meter of body-surface.[1]	
					Per hour.	Per minute.	Per hour.	Per minute.
	Kilos.	*cm.*	*Grams.*	*c. c.*	*Gram.*	*c. c.*	*Grams.*	*c. c.*
W. O. A.	84.7	168	23.5	199	0.278	2.35	9.9	83.9
D. W.	78.3	180	26.6	225	.339	2.88	11.8	100.0
J. C. W.	77.1	178	26.5	225	.338	2.92	11.9	100.9
H. C. K.	72.0	181	24.8	210	.344	2.92	11.6	98.8
A. L. L.	71.5	166	25.5	217	.357	3.03	12.0	102.2
H. F.	71.2	168	21.8	185	.307	2.61	10.3	87.7
A. W. S.	69.4	176	24.0	204	.345	2.94	11.5	98.0
E. O.	68.3	173	22.8	193	.333	2.83	11.1	94.0
N. M. P.	66.9	177	24.6	209	.368	3.12	12.1	102.9
B. F. D.	66.4	170	23.1	196	.347	2.95	11.4	97.0
C. R. Y.	66.1	170	25.0	212	.379	3.22	12.5	105.7
H. A.	64.1	170	27.5	233	.428	3.64	14.0	118.4
J. F. S.	64.0	171	22.4	191	.350	2.98	11.4	96.7
A. H. M.	61.6	179	19.4	165	.315	2.67	10.1	85.6
O. F. T.	57.2	168	24.0	204	.420	3.56	13.1	111.3
S. A. B.	57.0	166	19.9	169	.348	2.96	10.9	92.6
H. E. S.	56.6	178	22.8	193	.402	3.41	12.5	106.5
H. R. D.	56.2	171	21.1	179	.374	3.18	11.7	99.0
H. L. K.	55.0	166	19.4	165	.352	2.99	10.9	92.3
Average	....	....	23.4	199	.354	3.01	11.6	98.6

[1] In computing body-surface the formula of Meeh has been used: $12.312 \sqrt[3]{\text{body-weight}}$.

A number of writers, instead of expressing the carbon-dioxide production in grams per hour, have expressed it as cubic centimeters per minute, and in the fifth column of table 67 the values obtained with these individuals expressed as cubic centimeters per minute are given. The average carbon-dioxide production per minute per person was 199 c. c. The lowest was 165 c. c. with the subjects A. H. M. and H. L. K., and the highest 233 c. c. with the subject H. A.

Per kilogram of body-weight.—Researches in metabolism show that there is a distinct relationship between the body-weight of the subject and the metabolism, and as carbon dioxide is an index of the general metabolism it is important to compare experiments, not on the basis of individuals, but on the basis of per kilogram of body-weight. Consequently, in the experiments here reported, the calculations have been made per kilogram of body-weight per hour, and they thus give a more scientifically exact comparison with different individuals. The results are recorded in the sixth column of table 67. Gen-

erally speaking, about one-third of a gram of carbon dioxide per kilogram of body-weight per hour is excreted by an individual during sleep. The amounts in these experiments range from 0.278 gram in the case of the subject W. O. A., to 0.428 gram with the subject H. A. The average of all subjects is 0.354 gram. Expressing the results as cubic centimeters per minute, the experiments show that, per kilogram of body-weight, the average excretion per minute was 3.01 c. c. Variations are found ranging from 2.35 c. c. to 3.64 c. c.

Per square meter of body-surface.—As has been pointed out by Rubner and others, the metabolism is not directly proportional to the body-weight but more directly proportional to the body-surface, which bears a definite ratio to the body-weight.[1] Consequently, in these experiments the calculations have also been based on the carbon-dioxide excretion per square meter of body-surface per hour, thus attempting to bring the experiments more into comparison than by any other means. On the average, 11.6 grams of carbon dioxide are produced per square meter of body-surface per hour during sleep, the variations ranging from 9.9 grams with W. O. A. to 14 grams with H. A. Expressed in terms of cubic centimeters per minute, the carbon-dioxide excretion per square meter of body-surface varied with these subjects from 83.9 c. c. to 118.4 c. c., the average excretion being 98.6 c. c.

COMPARISON WITH OTHER INVESTIGATIONS ON CARBON-DIOXIDE ELIMINATION DURING SLEEP.

In comparing the results of these experiments with those of the earlier writers, it is necessary to draw a sharp distinction between experiments made with artificial mouthpieces or nosepieces and experiments made in which the subject, breathing normally, is inclosed in a large chamber without being obliged to give any particular attention to keeping the mouth tightly closed around a mouthpiece, or the face held against a mask.

It is quite inconceivable that even the most carefully trained subjects could sleep and at the same time exercise all the precautions necessary when a mouthpiece or mask is employed. Nevertheless, we find a number of experiments in the literature in which the sleeping production of carbon dioxide was determined with a greater or less degree of accuracy. Employing his respiration mask, Smith,[2] in 3 experiments, under conditions which the author describes as "whilst awake but after lying down for some hours and with every approach to sleep," exhaled carbon dioxide at the rate of 22.14, 22.92, and 23.70 grams, respectively, per hour. In another experiment in which he reports "light sleep, but probably not profound," he exhaled 19.08 grams per hour. In another experiment, in which he reports that he was asleep, he gave off 19.44 grams per hour.

[1] According to Meeh (*loc. cit.*), the body-surface is found by the formula $S = \sqrt[3]{W^2} \times 12.312$ in which S = body-surface in square centimeters and W = body-weight.

[2] Smith, Philosophical Transactions, 1859, **149**, p. 709; Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 104.

Using the mouthpiece with the Zuntz-Geppert respiration apparatus, Magnus-Levy[1] studied the respiratory exchange of a man (56.2 kilos) without food for a number of hours during the day. From $9^h 45^m$ p. m. to $10^h 30^m$ p. m., when the notes record that the man was asleep, the average carbon-dioxide production per minute was 147.1 c. c. From 1 a. m. to $1^h 40^m$ a. m., when the subject was in part asleep, the carbon-dioxide production averaged 152.5 c. c. per minute in 3 experiments. At $4^h 16^m$ a. m. and $4^h 39^m$ a. m., when the subject was reported as being but partly asleep, the carbon-dioxide excretion was very much larger, averaging 171.4 c. c.

In this laboratory it has been found extremely difficult to secure tight closure with the use of a mouthpiece, unless the subject gives particular attention to holding the mouthpiece in the proper position. Almost invariably when the subject is asleep the muscles of the face and jaw relax and there may be distinct opportunity for leakage of air around the mouthpiece; hence one must look askance at the results obtained during sleep with the mouthpiece or mask. On the other hand, when the subject is inclosed in an air-tight chamber with normal respiration, the error incidental to the measurement of the carbon-dioxide production during sleep does not result from imperfect closure of the mouth, and the co-operation of the subject himself is not needed for successful experiments.

In several experiments made with his respiration chamber, Scharling[2] had periods when the subjects were asleep, and the analyses were so made that the carbon-dioxide production during the sleeping periods could be observed with reasonable accuracy. From the results of these experiments, Scharling has concluded that with one subject weighing 65.5 kilos and 35 years of age, the carbon-dioxide production during sleep was 22.79 grams. With another subject 16 years of age and weighing 57.7 kilos, the carbon-dioxide during sleep was 26 grams. With another subject, 28 years of age and weighing 82 kilos, in 2 periods the carbon-dioxide production yielded 27.9 and 31.4 grams respectively.

Pettenkofer and Voit,[3] in an extensive series of experiments, separated the day and night periods, but the night was not a true sleeping period. They report that at night the subject lay in bed without eating any food and slept for 6 hours, so that the muscular exercise incidental to sitting in a chair and taking food was absent. While, therefore, the results they report are not, strictly speaking, obtained during sleep, they may be used for comparison. In 10 rest experiments during which the carbon-dioxide production was studied during the night period, the amounts per hour were as follows: 26, 26.3, 31.6, 33.7, 33.6, 35.2, 36.8, 27.6, 37.6, and 24.9 grams, respectively. All but the last experiment were made with the same subject, whose body-weight was approximately 70 kilos.

[1] Magnus-Levy, Archiv f. d. ges. Physiol., 1894, **55**, p. 35.
[2] Scharling, *loc. cit.*
[3] Pettenkofer and Voit, Zeitschr. f. Biol., 1866, **2**, p. 550.

In two of Liebermeister's experiments,[1] the subject slept during a portion of the time, and in the first experiment the carbon-dioxide production amounted to 24.6 grams per hour. In the second experiment, which was made a week later on the same subject, he found in 2 half-hour periods, when the subject was sleeping soundly, 25.4 and 24.6 grams of carbon dioxide per hour, respectively. The subject was 42 years of age, 177 cm. high, and weighed 68.5 kilos.

In 6 days of experimenting with a fasting subject, Sadovyen[2] found the carbon-dioxide excretion per hour during the night from 11 p.m. to 9 a.m. as follows: 29.7, 36.7, 32.7, 33, 28.5, and 27 grams, respectively. On one night, when the man took food, the carbon-dioxide production in that period was 32 grams per hour.

In the respiration apparatus of Hoppe-Seyler, there was no opportunity for the subject used by Laves[3] to lie down, and consequently, although 2 experiments are reported as having been made between 9 o'clock at night and 7 o'clock in the morning, it is highly probable that, although no direct evidence is presented, the subject was not soundly asleep. The carbon-dioxide production in these 2 experiments was 26 and 24.5 grams per hour, respectively.

By far the greatest number of experiments made during the night, aside from those conducted in the respiration calorimeter at Wesleyan University, were made in the research by Sondén and Tigerstedt.[4] In 11 experiments these investigators found that the carbon-dioxide production during sleep was 20.5, 21.5, 24.5, 19.5, 19.5, 21, 22, 27, 22, 25.5, and 24.5 grams per hour, respectively.

Lewin,[5] using the large Pettenkofer respiration apparatus in Munich, made 5 experiments with a man, in which the sleeping periods covered 8 to 9 hours. In these experiments, which were all made with a healthy workingman weighing 76 kilos, the carbon-dioxide production per hour was 26, 27, 25.5, 28, and 27 grams, respectively.

During one of the experiments reported by Jaquet in the description of his respiration apparatus,[6] the subject remained in the chamber throughout the night and from 10 p.m. to $2^h\,30^m$ a.m. he was sleeping, the greater part of the time deeply. During this experiment, 3 periods were obtained and the carbon-dioxide production per hour was 27.5, 25, and 23.1 grams, respectively.

Exercising especial precaution to keep quiet when not sleeping and thus making the experiments comparable, Staehelin[7] made a number of experiments on himself with the Jaquet respiration apparatus at Basel, studying particularly the influence of the ingestion of food. The experiments were all made during the night period, when the subject was lying quietly in bed and

[1] Liebermeister, Deutsch. Archiv f. klin. Med., 1870, **7**, p. 75.
[2] Sadovyen, *loc. cit.*
[3] Laves, Zeitschr. f. physiol. Chemie, 1894, **19**, p. 590.
[4] Sondén and Tigerstedt, *loc. cit.*
[5] Lewin, Zeitschr. f. Biol., 1881, **17**, p. 171.
[6] Jaquet, *loc. cit.*
[7] Staehelin, Zeitschr. f. klin. Med., 1906, **66**, p. 201.

usually asleep. The carbon-dioxide excretion in the first experiment, when no food had previously been taken, amounted to 19.9 grams per hour. The subject had a body-weight of 67.2 kilos. In 4 other experiments the carbon-dioxide excretion per hour from 8 p. m. to 8 a. m. was 23.5, 22.7, 24.1, and 25.8 grams, respectively. These experiments are somewhat complicated, however, as food was ingested immediately preceding some of the experiments.

While, as has been pointed out above, it is of doubtful value to compare experiments made with a subject in a closed chamber with those made on a sleeping subject wearing a mouthpiece, owing to the difficulties of guarding against leakage around the mouth or nose when the muscles of the face are relaxed, nevertheless the experiments made with our apparatus may properly be compared with experiments in which the Zuntz-Geppert apparatus was used with subjects awake. With the Zuntz-Geppert apparatus the subject, usually well-trained, lies quietly resting on a couch with the greatest muscular relaxation 12 hours after the last meal, and consequently the metabolism is at a very low point. For purposes of comparison, reference can be made to the table on page 156 which is copied directly from an article by Loewy.[1] These results are taken chiefly from the researches of Magnus-Levy and Falk and others of the Zuntz school. The average production of carbon dioxide per kilogram of body-weight per minute with these men was found to be 2.96 c. c., which agrees remarkably with the value obtained with men when sleeping in the respiration chamber at Wesleyan University, namely, 3.01 c. c. The carbon-dioxide production per square meter of body-surface can also be compared with the experiments made with the Zuntz-Geppert apparatus. Thus, the average of the experiments given in the table on page 156 was 95.7 c. c. per square meter per minute. The average of the results for the sleeping experiments here reported was 98.6 c. c.

The variations in the results obtained with the Zuntz-Geppert apparatus were somewhat larger than those obtained by us. Thus, the carbon-dioxide production per kilogram and per minute by the subjects in the table on page 156 ranged from 2.17 c. c. with subject No. 17 to 4.18 c. c. with subject No. 10. In the experiments on sleeping man reported by us the variations extend only from 2.35 c. c. to 3.64 c. c. Considering the excretion per square meter of body-surface per minute the variations in the table on page 156 ranged from 76.9 c. c. with subject No. 17 to 133.2 c. c. with subject No. 10, while with the sleeping men here reported the range is but from 83.9 to 118.4 c. c.

INFLUENCE OF PREVIOUS MUSCULAR ACTIVITY UPON THE CARBON-DIOXIDE ELIMINATION DURING SLEEP.

In many of the experiments made at Wesleyan University the night periods were preceded by day periods in which there were great variations in the muscular activity of the individuals. During the day the subject may have been at rest and either fasting or with food; or he may have had muscular

[1] Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1908, 4, p. 179.

exercise on a bicycle ergometer which varied from moderate work to very severe muscular work. In most of the experiments the carbon-dioxide production of these individuals under the different conditions can be compared, and the results are brought together in table 68. As an index of the amount of muscular exercise, the heat equivalent of work done expressed in calories is given in the footnote connected with the table.

An examination of table 68 shows that there was a distinct tendency for the carbon-dioxide production to be somewhat greater on the nights following work periods than on the nights following days when the subject was at rest, with the single exception of the experiments with J. F. S., in which there was an average difference of but 0.1 gram. With the other subjects, however, the tendency is marked, and particularly with the experiments where severe work and very severe work were carried out. Of special interest is, perhaps, the series of experiments with A. L. L. During 5 nights of rest after food, this subject exhaled on an average 24.2 grams of carbon dioxide. The average for 11 nights after severe work was 26.7 grams, and one night, when the work continued until 3 a. m., the carbon-dioxide production for the period from 4 a. m. to 7 a. m. was 28.4 grams per hour.

TABLE 68.—*Carbon dioxide eliminated during sleep (1 a. m. to 7 a. m.) following different conditions of activity.*

[Average per hour.]

Subject.	Sleep after rest.	Sleep after moderate work.	Sleep after severe work.	Sleep after very severe work.
	Grams.	*Grams.*	*Grams.*	*Grams.*
E. O.	22.6	[1]23.4	....	....
J. F. S.	22.4	[2]22.5	....	....
J. C. W.	25.8	....	[3]26.7	....
B. F. D.	22.7	....	[4]25.5	....
A. L. L.	24.2	....	[5]26.7	[6]28.4

[1] Heat equivalent of work done, 160 to 250 calories.
[2] Heat equivalent of work done, 130 to 280 calories.
[3] Heat equivalent of work done, 480 to 660 calories.
[4] Heat equivalent of work done, 420 calories.
[5] Heat equivalent of work done, 450 to 460 calories.
[6] Period 4 a. m. to 7 a. m. Heat equivalent of work done, 957 calories.

In this last experiment,[1] the subject rode a bicycle ergometer at a high rate of speed almost continuously from 8 a. m. until $3^h\ 01^m$ a. m. the next day, at which time he stopped work, changed underclothes, and at $3^h\ 20^m$ a. m. he was asleep. The carbon-dioxide production given in table 68 included the period from 4 a. m. to 7 a. m., with due allowance for the carbon dioxide residual in the chamber at the beginning and end of the period. Under these conditions the carbon-dioxide production of this man was 28.4 grams, which was very considerably higher than the carbon-dioxide production during sleep following severe muscular work or during sleep following rest with food.

[1] Benedict and Milner, U. S. Dept. Agr., Office Expt. Stas. Bul. 175, p. 105, experiment No. 64, 1907.

Obviously, the relatively small number of experiments here reported do not permit of any rigid conclusions in regard to the effect of previous muscular exercise upon the carbon-dioxide production during sleep. They do not accord with the observations of Higley and Bowen[1] who found an almost immediate return to the normal carbon-dioxide production value on the cessation of work. The latent period was in their experiments but 20 seconds. Marcet[2] also found in experiments on man that the carbon-dioxide production fell to the normal amount in from 6 to 7 minutes after the cessation of work.

In the experiments of Pettenkofer and Voit,[3] certain results for night periods both after rest and after work are given. In 2 experiments, for the night period following rest, the carbon-dioxide production for the 12 hours of the night was 312 and 316 grams, respectively. In an experiment with work, also without food, while the carbon-dioxide elimination during the day increased some 450 grams over the value at rest, the carbon-dioxide elimination during the night period fell to 257 grams. In a series of experiments with an average diet, the carbon-dioxide production during the night period of 4 experiments averaged about 400 grams. In 1 experiment with work, while the carbon-dioxide production during the day was 360 grams above the resting value, the carbon-dioxide production during the night remained exactly the same as in the experiments after rest. On the other hand, in a second work experiment while the carbon-dioxide excretion during the day increased about 300 grams over rest, there was a decrease of 100 grams in the carbon-dioxide excretion of the night period.

An interesting discussion of the after-influence of work on the carbon-dioxide production during rest is taken up by Sondén and Tigerstedt,[4] in which they cite the experiments of Speck,[5] Katzenstein,[6] and Zuntz and Lehmann[7] on this point. It is important to bear in mind, however, that the after-results of work in increasing the carbon-dioxide production in the experiments of Speck and Katzenstein usually did not last more than a few minutes; while in the experiments here reported with A. L. L., the measurement of the carbon-dioxide production did not begin until nearly 45 minutes after the subject was in bed and asleep.

As will be seen subsequently, the influence of the ingestion of food, the time of day at which the food is taken, and the character of the diet all play important rôles in the excretion of carbon dioxide. It is difficult to see how either the previous food or muscular exercise can affect the results during the sleeping period. One would naturally presume that after a day of severe

[1] Higley and Bowen, Amer. Journ. Physiol., 1905, **12**, p. 311.
[2] Marcet, Arch. des sci. phys. et nat. Genève, 1894, **31**, p. 21.
[3] Pettenkofer and Voit, Zeitschr. f. Biol., 1866, **2**, p. 459.
[4] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 169, *et seq.*
[5] Speck, *loc. cit.*, p. 59.
[6] Katzenstein, Archiv f. d. ges. Physiol., 1891, **49**, p. 330.
[7] Lehmann and Zuntz, Archiv f. pathol. Anatomie, 1893, **131**, supp. bd., p. 70.

muscular work, particularly after a day of such severe work as was performed in the experiment with A. L. L. previously referred to, the subject would sleep quietly and, indeed, more soundly than usual.

It is greatly to be regretted that during these experiments the pneumograph and stethoscope for counting the respiration-rate and heart-beat were not used, for it would have been extremely interesting to note the variations in pulse and the respiration-rate under the conditions cited above. The increased muscular tonus, which may continue for some time after severe muscular work, may account without further explanation for the noticeable increase in the carbon-dioxide production following severe, and very severe, muscular work. While it has commonly been believed that the carbon-dioxide production rapidly, and indeed almost immediately assumes a normal level after the work is finished, the evidence as set forth here would imply that there was a considerable increase in the carbon-dioxide excretion. This increase may be due to the excretion of previously formed carbon-dioxide, which is but slowly swept out of the system, or it may be due to the continuation of increased muscular tonicity and possibly increased metabolism following the stimulation resulting from the long-continued severe muscular work. The cause for this increase has not yet been settled, and the problem is certainly worthy of further experimentation.

MINIMUM ELIMINATION OF CARBON DIOXIDE DURING SLEEP.

In the data recorded in table 67, the values are all given for the period from 1 a. m. to 7 a. m., and it is there assumed that sleep was continuous throughout this period. The analyses were usually made in 2-hour periods, and consequently we have 3 periods during sleep in each night. An examination of the detailed statistics shows that in many instances there was a minimum production of carbon dioxide during these periods which is somewhat less than the average reported in table 67. It is of interest, therefore, to compare the minimum carbon-dioxide production of a number of individuals during the night. In the following statement the minimum carbon-dioxide elimination per hour by different individuals during sleep, between 1 a. m. and 7 a. m., is given. The lowest minimum carbon-dioxide production found for any individual in 1 hour during sleep was 15.3 grams on 1 night with the subject S. A. B. The highest minimum carbon-dioxide production is found to be 25.3 grams with the subject H. A.

	Grams.		Grams.		Grams.
W. O. A.	[1] 23.3	E. O.	[1] 19.9	O. F. T.	[1] 22.7
D. W.	24.1	N. M. P.	23.5	S. A. B.	15.3
J. C. W.	21.0	B. F. D.	20.1	H. E. S.	20.5
H. C. K.	22.3	C. R. Y.	22.9	H. R. D.	18.3
A. L. L.	20.6	H. A.	25.3	H. L. K.	17.5
H. F.	[1] 19.5	J. F. S.	[1] 21.0		
A. W. S.	[1] 21.8	A. H. M.	17.4		

[1] Average per hour in minimum 6-hour period.

The foregoing statement shows very strikingly the variation in carbon-dioxide excreted by different individuals, even under like conditions of muscular activity and rest. It must be borne in mind that the experiments from which these data were drawn were made during the period from 1 a. m. to 7 a. m., when the subjects were supposed to be covered and quietly lying asleep in the respiration chamber. In the large majority of instances they had been accustomed to the chamber for some time previous, and we have every reason to believe that the sleep was normal and somewhat profound.

The question as to whether sleep *per se* has any influence upon metabolism has been considered in great detail by Johansson,[1] who, as a result of a most rigid series of experiments, by voluntary control of muscular movements was able to reduce the carbon-dioxide production to practically a constant value throughout the whole 24 hours. In all probability, outside of the possibilities of more complete muscular relaxation and quietude, sleep of itself has no influence on metabolism. As may be seen in a later discussion, any factors that reduce muscular tonus or decrease the respiration-rate or heart-beat tend to decrease the metabolism, and in so far as sleep produces these results, it can possibly be considered as directly affecting metabolism. It is apparent, therefore, from the results of the experiments here reported, that the problem of metabolism during sleep presents many interesting features, but it is also obvious that experiments during sleep should be accompanied by careful records of the pulse- and respiration-rates, and, if possible, of the blood-pressure and bodily movements, in order to make the value comparable. Due regard should be given to the preceding diet, and of prime importance also, in studying the carbon-dioxide excretion are the chemical data which will allow the apportionment of the oxidation between glycogen and fat during the resting period. Until all of these conditions are met with results can have but a tentative value.

CARBON-DIOXIDE ELIMINATION DURING WAKING HOURS.

From the results of the consideration of the carbon-dioxide production during sleep it is easy to conceive that differences in the amounts of carbon dioxide excreted by individuals during waking hours may be very great, even under conditions approximating uniformity so far as muscular activity and diet are concerned.

Although the experiments from which these data are derived were so-called rest experiments, *i. e.,* with no external muscular work, the variations in the amount of carbon dioxide produced are noticeable. The men were supposed, for the most part, to be sitting quietly in a chair or moving about the narrow confines of a small respiration chamber during the day. In certain experiments the men remained seated during the whole day. In others, they lived more or less normally, but were required to move occasionally, as to go from the chair to the food aperture, to lie down at times on the bed, or to rise and sit in the

[1] Johansson, Skand. Archiv f. Physiol., 1898, 8, p. 85.

chair. In some experiments food was eaten in small amounts, and in others no food was taken. Since, however, the subject of carbon-dioxide excretion during fasting has received especial attention,[1] the emphasis in this discussion is laid upon the experiments where the subjects were more or less in a state of digestion.

TABLE 69.—*Carbon dioxide eliminated during waking hours by different individuals in rest experiments.*

Subject.	Body-weight (without clothing).	Height.	Amount per hour.	Amount per minute.	Per kilogram of body-weight.		Per square meter of body-surface.[1]	
					Per hour.	Per minute.	Per hour.	Per minute.
	Kilos.	*cm.*	*Grams.*	*c. c.*	*Gram.*	*c. c.*	*Grams.*	*c. c.*
H. C. M.	86.3	166	38.3	325	0.444	3.76	15.9	135
W. O. A.	84.8	168	38.1	324	.450	3.82	16.0	136
F. G. B.	83.2	183	38.2	324	.459	3.89	16.3	138
D. W.	77.4	180	34.0	288	.440	3.73	15.2	129
G. G. R.	77.2	178	37.5	318	.486	4.10	16.8	143
J. C. W.	75.8	178	33.5	285	.443	3.76	15.2	129
S. C. D.	74.9	178	35.3	299	.472	4.00	16.1	137
W. R. L.	74.9	198	39.5	335	.528	4.45	18.0	153
W. E. D.	74.4	179	39.5	335	.531	4.50	18.1	154
F. C. B.	73.6	183	36.5	309	.496	4.21	16.9	143
H. C. K.	72.6	181	29.6	251	.409	3.47	13.8	117
H. F.	71.2	168	29.9	254	.421	3.57	14.2	120
A. L. L.	70.8	166	30.2	257	.426	3.62	14.3	122
R. D. M.	70.4	178	32.7	278	.464	3.92	15.5	132
A. W. S.	69.7	176	38.6	327	.554	4.70	18.5	157
J. R.	69.2	183	37.6	319	.544	4.59	18.1	153
N. M. P.	69.1	177	35.7	303	.515	4.38	17.2	146
E. O.	68.2	173	37.7	320	.552	4.68	18.3	155
A. M.	66.9	175	36.5	310	.546	4.64	18.0	153
B. F. D.	66.4	170	34.4	292	.518	4.40	17.0	144
C. R. Y.	66.4	170	33.9	287	.513	4.35	16.8	141
H. D. A.	66.2	181	34.3	291	.518	4.40	17.1	145
N. B.	66.0	172	29.0	246	.440	3.73	14.4	123
R. A. M.	65.0	166	34.8	295	.536	4.53	17.5	148
A. H. M.	64.3	179	26.9	229	.420	3.56	13.6	116
H. A. P.	64.3	180	30.2	256	.469	3.98	15.3	130
F. L. T.	64.3	192	37.0	314	.576	4.86	18.7	159
E. M. S.	64.3	175	32.5	275	.506	4.29	16.4	140
H. A.	64.1	170	34.3	291	.535	4.54	17.4	148
J. F. S.	63.4	171	36.0	306	.568	4.82	18.4	156
W. H. L.	63.2	174	34.7	295	.549	4.66	17.8	151
J. V. C.	63.2	173	33.2	282	.526	4.47	17.0	145
G. E. H.	63.2	179	26.8	228	.425	3.61	13.8	117
J. N. T.	63.1	173	38.8	329	.616	5.23	19.9	169
D. R. F.	62.4	173	33.3	283	.534	4.53	17.2	146
A. G.	62.3	170	35.0	297	.562	4.78	18.2	154
C. F. B.	62.2	170	35.9	305	.578	4.92	18.6	158
J. W. H.	60.9	175	39.6	336	.650	5.52	20.8	176
J. A. R.	59.2	180	30.9	263	.523	4.45	16.6	141
C. A. R.	59.0	174	32.4	275	.549	4.66	17.3	147
H. C. A.	58.9	172	32.4	275	.550	4.67	17.4	147
F. W. H.	58.4	173	31.2	265	.534	4.51	16.8	142
F. N. C.	57.6	168	33.9	287	.588	4.99	18.5	157
H. R. D.	57.5	171	25.9	220	.451	3.82	14.1	120
H. E. S.	57.2	178	27.4	233	.479	4.07	15.0	127
O. F. T.	57.2	168	38.5	326	.672	5.70	21.0	178
S. A. B.	56.4	166	26.2	223	.465	3.94	14.4	123
J. T. H.	56.0	170	29.6	251	.529	4.48	16.4	140
H. L. K.	55.6	166	31.3	265	.562	4.77	17.4	148
F. E. R.	52.2	168	29.1	247	.559	4.74	17.0	144
H. L. W.	51.8	164	29.2	248	.564	4.80	17.0	145
G. H. H.	51.7	163	31.4	267	.609	5.17	18.4	156
G. W. S.	51.5	173	29.3	248	.568	4.83	17.2	146
T. M. C.	50.5	166	27.5	233	.545	4.62	16.4	139
H. G.	49.2	160	27.6	234	.561	4.77	16.7	142
B. N.	46.4	168	30.7	261	.662	5.60	19.3	164
Average	....	....	33.3	282	.521	4.42	16.9	148

[1] In computing body-surface the formula of Meeh has been used: $12.312 \sqrt[3]{\text{body-weight}}$.

[1] Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 438.

The results of the carbon-dioxide excretion during sleep are, as has been pointed out, comparable with those made with the Zuntz-Geppert respiration apparatus during complete muscular relaxation when lying on a couch. The results obtained in the experiments in which the subjects were awake sitting up in a chair are obviously considerably higher, but, on the other hand, they more truly represent the carbon-dioxide production of a subject sitting awake and resting quietly. The results are presented in table 69. The largest amount measured was with the subject J. W. H., 39.6 grams per hour, or 336 c. c. per minute. The smallest amount was that with the subject H. R. D., 25.9 grams per hour or 220 c. c. per minute. This table indicates that the average carbon-dioxide excretion per hour for a normal man when sitting and resting is 33.3 grams of carbon dioxide per hour or 282 c. c. per minute. As has been pointed out, these values have no relation whatever to the body-weight of the individual, and for purposes of comparison it is more advantageous and physiologically more correct to compute the values on the basis of per kilogram of body-weight per hour and per square meter of body-surface.

Per kilogram of body-weight.—Dividing the total hourly excretion by the body-weight, we have the carbon dioxide produced per kilogram of body-weight per hour. On this basis the largest amount is with the subject O. F. T., or 0.672 gram per hour; the smallest is with the subject H. C. K., or 0.409 gram per hour. The average of all the subjects is 0.521 gram per hour. Using the other method of expressing the amount per kilogram of body-weight, namely, in cubic centimeters per minute, we have variations from 5.70 c. c. with O. F. T. to 3.47 c. c. per minute with H. C. K. The average for all the subjects was 4.42 c. c. per kilogram per minute.

Per square meter of body-surface.—The largest amount expressed in these terms is likewise found with the subject O. F. T., or 21 grams per square meter of body-surface per hour. The smallest amount was found with A. H. M., *i. e.,* 13.6 grams per hour. The average of all subjects was 16.9 grams per hour. Expressing the results in terms of cubic centimeters per minute per square meter of body-surface, we have 178 c. c. with O. F. T. and 116 c. c. with A. H. M., the average of all subjects being 143 c. c. per square meter per minute.

RATIO OF CARBON-DIOXIDE ELIMINATION DURING SLEEP TO THAT DURING WAKING HOURS.

While all of the experiments here reported are distinctly rest experiments, with a minimum amount of muscular work, nevertheless, there is a noticeable difference between the muscular activity when the subjects are lying quietly in bed covered and sound asleep, and when they are sitting in a chair turning over the pages of a book or moving about the chamber attending to food, dishes, etc. There is a marked difference in the muscular activity between the day and the night, and consequently the carbon-dioxide production during these periods varies considerably. For the subjects with which we have experiments

during both the day and the night, the results have been collected and presented in table 70. The average carbon-dioxide production during sleep per hour is given in the first column, and that during the waking hours with the subject at rest in the second. The results in the first two columns are copied from tables 67 and 69, and the ratio of sleeping to waking is shown in the last column. If the value when asleep is taken as 100, it is seen that the value when at rest and awake may vary from 118 to 165. The total average shows a ratio of 100 : 140.

TABLE 70.—*Ratio of carbon dioxide eliminated during sleep to that eliminated during waking hours in rest experiments.*

Subject.	(a) Amount per hour during sleep.	(b) Amount per hour during waking hours.	(c) Ratio sleeping to awake. (b+a)	Subject.	(a) Amount per hour during sleep.	(b) Amount per hour during waking hours.	(c) Ratio sleeping to awake. (b+a)
	Grams.	*Grams.*			*Grams.*	*Grams.*	
W. O. A.	23.5	38.1	100 : 162	H. A.	27.5	34.3	100:125
D. W.	26.6	34.0	128	J. F. S.	22.4	36.0	161
J. C. W.	26.5	33.5	126	A. H. M.	19.4	26.9	139
H. C. K.	24.8	29.6	119	O. F. T.	24.0	38.5	160
A. L. L.	25.5	30.2	118	S. A. B.	19.9	26.2	132
H. F.	21.8	29.9	137	H. E. S.	22.8	27.4	120
A. W. S.	24.0	38.6	161	H. R. D.	21.1	25.9	123
E. O.	22.8	37.7	165	H. L. K.	19.4	31.3	161
N. M. P.	24.6	35.7	145				
B. F. D.	23.1	34.4	149	Average	23.4	82.7	100:140
C. R. Y.	25.0	33.9	136				

This ratio has been discussed at considerable length by Sondén and Tigerstedt.[1] In 6 experiments with normal diet the ratios found by Sondén and Tigerstedt were 100 : 144, 137, 147, 151, 169, and 138, respectively. Without food the ratios in 5 experiments were 100 : 156, 142, 136, 132, and 143, respectively. The average of the experiments with normal diet was 100 : 148; without food, 100 : 142, with an average of 100 : 145, a value agreeing almost identically with that found in the experiments here reported.

Mention should be made here of the relationship between the day and the night as found in the experiments of Pettenkofer and Voit, although, as has been pointed out previously, the carbon-dioxide excretion was not, strictly speaking, during sleeping periods.[2] The ratios found in their 10 experiments on a healthy man were 100 : 137, 120, 141, 133, 131, 137, 135, 154, 107, and 132, respectively, the average of all these ratios being 100 : 135.

CONCLUSIONS WITH REGARD TO THE ELIMINATION OF CARBON DIOXIDE.

From the results of these experiments it is evident that individuals vary materially in the carbon-dioxide production during the day, and even when considered on the basis of body-weight or body-surface there are still noticeable variations. That these variations are in large part due to variations in the

[1] Sondén and Tigerstedt, *loc. cit.*, p. 148.
[2] Pettenkofer and Voit, Zeitschr. f. Biol., 1866, 2, p. 546.

preceding diet, in minor muscular activity, and, in experiments where no food is taken, to the previous storage of glycogen, seems to be quite clear. The influence of the ingestion of food upon metabolism has been the subject of a large number of experiments in the laboratory at Wesleyan University and in the Nutrition Laboratory at Boston.

Aside from the influence of minor muscular activity, the state of digestion and temperament of the individual, even during periods of the day when both the minor muscular activity and the digestion are at a minimum, there further exist marked differences in the amounts of carbon dioxide excreted by different individuals. This is true even when the results are computed on the basis of per kilogram of body-weight or per square meter of body-surface. These differences are especially well shown during the night periods, and the results are so at variance that it seems to be clearly shown that the carbon-dioxide excretion, as such, can not be considered as a constant quantity. What influences the carbon-dioxide production during sleep is at present only a matter of speculation, although the proportion of the active mass of protoplasmic tissue probably plays an important rôle. The results of a number of unpublished experiments which were made 12 hours after the last meal show that the previous store of glycogen may play an important rôle in the carbon-dioxide production during the night.

With some individuals there is a large store of glycogen; this is easily drawn upon and consequently the carbon-dioxide production during the night may be large. In others the store of glycogen may be small, and fat will be used to supply the energy during the night periods. This is obviously not to be interpreted as meaning that the energy is derived either wholly from glycogen or wholly from fat in any one individual, but that the relative amounts of fat and glycogen katabolized during the night may vary considerably in proportion to the previous store of glycogen in the body of the subject of the experiment. This type of apparatus, *i. e.*, a large respiration chamber, and the conditions which existed during most of the experiments here reported, are not ideal for studying this particular problem, and investigations now in progress in the Nutrition Laboratory will, it is hoped, throw light upon the storage of glycogen during the night period and its effect upon the carbon-dioxide production. Experiments of this nature are much needed, for not only is the carbon-dioxide production during the night period from 1 a. m. to 7 a. m. of prime importance, but more especially the carbon-dioxide production during the early waking hours from 7 o'clock to noon, since a large number of experiments with various types of respiration apparatus have been made during this period, 12 hours after the last meal, and the values thus found have been used as a basis for subsequent scientific researches.

OXYGEN CONSUMPTION.

While the determination of the carbon dioxide excreted by man presents no especially difficult problems other than the acurate analysis of the air, and the measure of the total air expired, the case is very different when an attempt is made to determine the total amount of oxygen consumed by man in any given experimental period.

METHODS FOR DETERMINING THE OXYGEN CONSUMPTION.

INDIRECT METHOD.

Two methods have been used to obtain this value; one, the so-called indirect, and the other the direct method. By the indirect method, careful records of the changes in body-weight, weights of the total food and drink ingested and feces and urine collected are made, and the total amounts of carbon dioxide excreted and water vaporized are carefully determined. From these data a simple calculation serves to show the oxygen consumption. The method was first brought into prominence by Pettenkofer and Voit and has since been used with considerable success by the Russian investigators, Sadovyen and Likhatscheff.

The errors incidental to measuring each of the numerous factors which must enter into the calculation of the oxygen by the indirect method are so great that without the most careful technique the values obtained can only be considered as rough approximations. The error of Pettenkofer and Voit in attributing what subsequently proved to be a change in weight of the bedding of the subject to a storage of oxygen in the body accentuates the difficulties attending the use of the indirect method for determining oxygen.

DIRECT METHOD.

The second method involves the direct determination of oxygen used by the subject. This may be done in two ways, first, by using a special nosepiece or mouthpiece and carefully analyzing the inspired and expired air, or by measuring the deficiency in oxygen in a large mass of air in which the subject remains seated at rest or at work. The first is the basis of the methods of Speck,[1] Zuntz-Geppert,[2] Hanriot and Richet,[3] and Chauveau and Tissot,[4] all of whom used a special mouthpiece or nosepiece. Instead of using such an apparatus, Jaquet[5] places his subjects in a large chamber, but by means of the most delicate gas-analysis apparatus analyzes the incoming and outgoing air, and notes the difference in the percentage of oxygen. Grafe[6] has employed Jaquet's method, but the subject wears a helmet, instead of being inclosed in a large respiration chamber. The principle involved in the determination of the oxygen remains, however, the same.

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[1] Speck, Physiologie des Menschlichen Athmens, Leipzig, 1892.
[2] Zuntz and Geppert, see detailed description by Magnus-Levy, Archiv f. d. ges. Physiol., 1894, **55**, p. 1.
[3] Hanriot and Richet, Comptes rendus, 1887, **104**, p. 435.
[4] Chauveau and Tissot, Comptes rendus, 1899, **129**, p. 249.
[5] Jaquet, Verhandl. Naturf. Gesellsch. Basel, 1904, **15**, p. 252.
[6] Grafe, Deutsch. Archiv f. klin. Med., 1909, **95**, p. 529.

The other direct method mentioned above is that used first by Regnault and Reiset[1] on small animals, which was subsequently elaborated and modified by Hoppe-Seyler[2] for use with man. More recently Zuntz and Oppenheimer[3] have constructed an apparatus on this principle for use with small animals or with infants. The apparatus has already been used in studying the metabolism of infants.[4] The principle is the basis of the method employed in the experiments here reported. In these experiments the subjects lived in a chamber through which a current of air was continually passed, the carbon dioxide and water-vapor given off being absorbed, and the air returned to the respiration chamber after the deficiency in oxygen had been made up by admitting pure oxygen from a cylinder of the compressed gas.

The methods employing the special mouthpiece or nosepiece or, indeed, the helmet, are hardly applicable to experiments of long duration. The apparatus of Jaquet, involving as it does the analysis of the incoming and outgoing air, is extremely practical and should find more extended use especially in hospital clinics. It is open to the objection that the deficiency in oxygen is usually but a few tenths of a per cent, for example, $20.92 - 20.16 = 0.76$ per cent, and hence an error in analysis, even when using the extremely delicate Pettersson apparatus, may involve an error of 2 to 5 per cent in the oxygen determination.

EARLIER INVESTIGATIONS.

Of the early researches on the consumption of oxygen by man, none antedate those of Lavoisier and Seguin.[5] In their remarkable memoir of 1789 they quote experiments to show that when a man is fasting and in a state of repose at a temperature of 26° R. he consumes per hour 1210 "cubic pouces" (24 liters) of oxygen. This is increased by cold, as under the same conditions of fast and rest, but with a temperature of 12° R. he consumes 1344 cubic pouces (26.7 liters) of oxygen per hour. During digestion this is increased from 1800 to 1900 cubic pouces (37.7 liters) per hour. Muscular exercise also increases it; thus Seguin, fasting and performing work, raised his oxygen consumption to 3200 cubic pouces (63.5 liters) per hour. The same exercise during digestion raised the oxygen consumption to 4600 cubic pouces (91.2 liters) per hour. The conversion of the old French values, cubic pouces, to liters was made by Gavarret.[6] The values are also given by Sondén and Tigerstedt.[7]

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[1] Regnault and Reiset, Ann. de Chimie et de Physique (3), 1849, **26**.
[2] Hoppe-Seyler, Zeit. physiol. Chem. 1894, **19**, p. 574.
[3] Zuntz and Oppenheimer, Englemann's Archiv für Physiol. Abt. 1905, Suppl. band, p. 431.
[4] Schlossmann, Oppenheimer and Murschhauser, Biochemische Zeitschrift, 1908, **14**, p. 385.
[5] Lavoisier and Seguin, *loc. cit.*
[6] Gavarret, Physique Medicale, Paris, 1855, p. 330.
[7] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 165.

As will be seen by a subsequent comparison, these results are remarkably concordant with those obtained at the present day by the most improved methods. Unfortunately, it is impossible for us to state by what method Lavoisier and Seguin obtained these remarkable results. We have no indication whatever of the nature of the apparatus, other than the two drawings by Madame Lavoisier.[1] The results certainly have great historic interest, and the wonder is that the values found thus early agree so remarkably well with those found at the present date under like conditions of bodily activity.

Although innumerable observers have made a large number of experiments on the composition of the expired air, noting the deficiency in oxygen and increase in carbon dioxide, the results in no wise contribute to our knowledge of the total oxygen consumption of man in any given experimental period, and it was not until the advent of the method devised by Speck,[2] in which spirometers were used, that we have accurate observations on this point. Speck's measurements covered a series of some 25 years and the experiments numbered hundreds.

Speck, as the result of a large number of experiments on himself, concludes that his normal oxygen consumption per minute is 285 c. c., his body-weight being about 60 kilos. In studying a series of normal individuals by means of this apparatus, he obtained 229 c. c. per minute as the oxygen absorption of a 20-year-old woman, weighing 47 kilos; a 17-year-old girl, weighing 52 kilos, absorbed 269 c. c. per minute; a 17-year-old boy, weighing 55 kilos, 334 c. c.; a 24-year-old woman, weighing 58 kilos, 234 c. c.; a 50-year-old man, weighing 62 kilos, 284 c. c.; a 31-year-old man, weighing 72 kilos, 330 c. c.; and a 57-year-old man, weighing 62 kilos, 245 c.c. Henrijean[3] reports that the oxygen consumption of a man, weighing 66 kilos, and 22 years of age, varied from 201 to 266 c. c. per minute 12 hours after the last meal. Speck criticises severely the method by which these results were obtained.

The results of the numerous investigators using the Zuntz-Geppert apparatus have been collected in table 64, on page 156 of this report. In this table it is seen that with 19 normal subjects the oxygen consumption per person per minute varied from 177 to 336 c. c., the average for the 19 subjects being 237 c. c. Expressed in terms of per kilogram of body-weight and per minute, the oxygen consumption varied from 2.76 to 5.50 c. c., averaging 3.79 c. c. per minute. On the basis of per square meter of body-surface, the oxygen consumption per minute varied from 97.5 c. c. to 176.1 c. c., the average for all subjects being 121.7 c. c. per minute.

By means of apparatus employing a mouthpiece and 3 gas-meters, Hanriot and Richet[4] made a number of experiments, from which they drew the conclusion that an adult man absorbs 0.45 gram of oxygen per kilogram of body-

[1] Grimaux, *loc. cit.*
[2] Speck, Physiologie des menschlichen Athmens, Leipzig, 1892.
[3] Henrijean, Bul. de l'acad. Belg., 1883, p. 113. Cited by Speck, p. 222.
[4] Hanriot and Richet, *loc. cit.*

weight per hour, or 5.25 c. c. per kilogram of body-weight per minute when in a state of fasting. In a state of digestion they conclude that there is an absorption of 0.50 gram of oxygen per kilogram per hour or 5.84 c. c. per kilogram per minute.

By means of the large respiration apparatus of Hoppe-Seyler, Laves[1] made 7 experiments on the same individual, lasting from 8 to 24 hours. Calculating the total amount of oxygen consumed in 24 hours, he found that the results in the different experiments varied from 357.2 liters to 445 liters for 24 hours or 3.725 c. c. to 4.585 c. c. per kilogram and per minute. In the 2 experiments in which the experimental period covered 24 hours, the results were totals of 409.5 liters and 391 liters, respectively, or 4.247 c. c. and 4.059 c. c. per kilogram of body-weight per minute. In this apparatus the oxygen was directly determined.

In the original description of his apparatus, Jaquet[2] gives the results of 2 experiments with man in which the oxygen consumption per hour was directly determined. In 1 experiment with a subject 32 years of age, and weighing 59.5 kilos, the hourly oxygen consumption from 8 a. m. until 7 p. m. was 23.2, 24.6, 31.9, 27.6, 29.7, 31.2, 29.1, 26.5, 27.2, 25.8, and 25.4 grams, respectively. With a second subject, 52 years of age, weighing 55 kilos, the experiment continued from 7 p. m. until 3 a. m., and the oxygen consumption per hour was during the 8 periods as follows: 32.3, 35.1, 32, 25.1, 27.7, 28.4, 27, and 23.7 grams, respectively.

Using the Jaquet apparatus in Basel, Staehelin[3] made 5 experiments with himself and obtained the oxygen calculated on the basis of 12 hours. The experiments were all made during the night, when the subject was asleep or resting quietly, covered, in the respiration chamber, after having partaken of a particular diet or, as in 1 experiment, 12 hours after the last meal. In the fasting experiment the oxygen consumption during the 12 hours of the night was 209.4 grams. In the experiment with a meal containing protein it increased to 270.56 grams for 12 hours; in the meal containing fat, 262.64 grams; in the meal with rice, 257 grams, and in the meal with protein and rice, 283.42 grams.

Describing his substitution of a helmet for the more elaborate respiration chamber in the Jaquet respiration apparatus, Grafe[4] reports experiments in which he concludes that on the average, adult man absorbs 4.04 c. c. of oxygen per minute and per kilogram of body-weight in a healthy individual.

[1] Laves, Zeitschr. f. Physiol., 1894, **19**, p. 602.
[2] Jaquet, *loc. cit.*
[3] Staehelin, Zeitschr. f. klin. Med., 1906, **66**, p. 201.
[4] Grafe, Deutsch. Archiv f. klin. Med., 1909, **95**, p. 541.

EXPERIMENTS ON OXYGEN CONSUMPTION.

APPARATUS AND METHODS USED.

The respiration apparatus formerly at Wesleyan University was so modified as to include the determination of oxygen, and a description of the apparatus was published in 1905.[1] The first experiments made with this apparatus including the determinations of oxygen were published in 1907.[2] The results there reported, together with the results of a series of experiments on fasting man,[3] are included in the tables in the discussion beyond, and hence will not receive special treatment here. As in the case of the experiments on carbon-dioxide production and water vaporization, only those portions of the fasting experiments that included the preliminary night and the first 24 hours are included in the tables herewith. Usually the last meal was taken the evening before at 6 or 7 o'clock; the observations began at 11 p. m. that night, and the next morning at 7 a. m., the first fasting-day began and continued for 24 hours.

As is to be expected in experiments in which so difficult a determination as that of oxygen was attempted, a number of them gave results which were plainly at variance with the normal—variations accounted for in all cases by the presence of a previously unsuspected leakage of air, hence they are not included in the averages. This is particularly true of some of the experiments of short duration. In experiments of 24 hours or more, we believe that the determinations of oxygen with this apparatus are extremely accurate, and in experiments of short duration where the subjects remained in the same bodily activity at the beginning and end of each experiment, we believe that the results are likewise accurate. But in a period, for example, between 11 p. m. and 1 a. m., where at 11 p. m. the subject is sitting in a chair, clothed, and at 1 a. m. he is lying partially undressed, covered with bedding, there may be such a marked difference in the temperature conditions inside of the chamber, more particularly in the temperature gradient, that the determination of oxygen may be seriously at fault.[4]

OXYGEN CONSUMPTION DURING SLEEP.

As has been pointed out previously, the sleeping period from 1 a. m. to 7 a. m. offers an exceptionally advantageous period for the study of the gas-exchange of man inside a large respiration chamber. The bodily position of the subject at 7 a. m. is usually the same as that at 1 a. m. and the subject is usually in a profound sleep. Results have been obtained during the night period with 15 subjects, and with some of them a large number of experiments were made; with others but one. The results have been collected in table 71 herewith. For pur-

[1] Atwater and Benedict, Carnegie Institution of Washington Publication No. 42, 1905.
[2] Benedict and Milner, U. S. Dept. Agr., Office Expt. Stas. Bul. 175, 1907.
[3] Benedict, Carnegie Institution of Washington Publication No. 77, 1907.
[4] For a discussion of these sources of error, see Benedict and Milner, U. S. Dept. of Agr., Office Expt. Stas. Bul. 175, pp. 24–32, 1907; and Benedict, Carnegie Institution of Washington Publication No. 77, p. 448, 1907.

poses of comparison, the body-weight and height are likewise given. The amount of oxygen consumed per hour by man varied in these experiments from 17.7 grams with the subjects S. A. B. and H. L. K., to 25.9 grams with the subject H. A. The average of all the subjects was 21.3 grams per hour. It is to be understood that these values represent the average of the period from 1 a. m. to 7 a. m. Usually this period was subdivided into three 2-hour periods.

Expressing the results according to the method which is more commonly used by writers, namely, as cubic centimeters per minute, we find the lowest oxygen consumption is 206 c. c. and the highest 302 c. c., the average for all the subjects being 249 c. c. of oxygen per minute.

TABLE 71.—*Oxygen consumed during sleep by different individuals (1 a. m. to 7 a. m.).*

Subject.	Body-weight (without clothing).	Height.	Amount per hour.	Amount per minute.	Per kilogram of body-weight.		Per square meter of body-surface.[1]	
					Per hour.	Per minute.	Per hour.	Per minute.
	Kilos.	*cm.*	*Grams.*	*c. c.*	*Gram.*	*c. c.*	*Grams.*	*c. c.*
W. O. A.	84.7	168	21.2	248	0.251	2.92	8.9	104
D. W.	78.3	180	24.2	282	.309	3.61	10.7	125
J. C. W.	76.5	178	24.3	283	.318	3.71	11.0	128
H. C. K.	72.0	181	21.9	256	.305	3.55	10.3	120
A. L. L.	71.4	166	23.1	270	.324	3.78	10.9	127
H. F.	71.0	168	19.9	232	.280	3.27	9.4	110
N. M. P.	66.9	177	21.7	253	.325	3.79	10.7	125
B. F. D.	66.4	170	20.1	235	.303	3.54	10.0	116
C. R. Y.	66.1	170	21.9	256	.332	3.87	10.9	127
H. A.	64.1	170	25.9	302	.403	4.70	13.1	153
A. H. M.	61.6	179	18.6	217	.302	3.53	9.7	113
S. A. B.	57.0	166	17.7	206	.310	3.61	9.7	113
H. R. D.	56.2	171	19.2	224	.342	3.99	10.6	124
H. E. S.	56.1	178	22.4	261	.399	4.66	12.4	145
H. L. K.	55.0	166	17.7	206	.322	3.75	9.9	116
Average	....	....	21.3	249	.322	3.75	10.5	123

[1] In computing body-surface the formula of Meeh has been used: $12.312 \sqrt[3]{\text{body-weight}^2}$.

Per kilogram of body-weight.—That there may be variations in oxygen consumption due to variations in the size of the individual is easily conceivable, and it is only when the results are compared on the basis of per kilogram of body-weight per hour that we have a proper classification. The results have been so calculated and they are presented in table 71. It is seen that the minimum absorption of oxygen per kilogram per hour was with the subject W. O. A., namely, 0.251 gram. The largest amount was with the subject, H. A., 0.403 gram. The average for all subjects showed an oxygen absorption per kilogram per hour of 0.322 gram, somewhat less than the carbon-dioxide production, 0.354 gram, under similar conditions. In converting these results to cubic centimeters per kilogram of body-weight per minute, the lowest is 2.92 c. c. and the highest 4.70 c. c. The average for all the subjects is 3.75 c. c., as against 3.01 c. c. of carbon dioxide under the same conditions.

Per square meter of body-surface.—Making due allowance for the fact that body-surface does not vary directly with the body-weight, the results per square meter of body-surface per hour have been computed for these subjects. The

oxygen consumption on this basis varies from 8.9 grams with W. O. A. to 13.1 grams with H. A., the average for all subjects being 10.5 grams. Converting these values to cubic centimeters per square meter of body-surface per minute, we have 104 c. c. as the minimum and 153 c. c. as the maximum, the average for all subjects being 123 c. c. of oxygen absorbed per square meter of body-surface per minute.

The variations in the amounts of carbon dioxide excreted by different individuals are in part explained in that the quantities of carbon dioxide excreted are influenced in large part by the nature of the materials burned during the experiment. While there may be large differences in the carbon-dioxide production with the same individual and with different individuals when compared on the basis of per kilo and per square meter, on the other hand it is commonly supposed that the oxygen absorption remains relatively constant, and with like body activity the same individual would absorb the same amount of oxygen, and different individuals would absorb relatively the same amount of oxygen per kilogram of body-weight. In these experiments the variations in the oxygen consumption are so noticeable that they can be explained only on the basis that there were marked differences in the actual katabolism with different individuals. Furthermore, an examination of data not presented in this table shows that with the same individual there may be during the sleeping period likewise noticeable differences in the oxygen consumption. This statement is, indeed, somewhat at variance with a statement made in the earlier part of this report in which the uniformity of results with the same individual has been emphasized (see page 106). Where variations in the oxygen consumption do occur, the only explanation that can be made is that there were actual differences in the katabolism, which may be affected by factors such as restlessness during sleep or, indeed, the influence of the preceding muscular exertion. (See discussion of this point on page 183.) It is also of importance to note here that an examination of the results in table 90 showed that in general the respiratory quotients remained relatively constant throughout the night experiments. Consequently, the variations in the carbon-dioxide production noted in these experiments must likewise be taken as being affected not so much by changes in the kind of material burned but by changes in the total amount of material burned, a change induced by a variation of the total katabolism.

COMPARISON WITH OTHER INVESTIGATIONS ON OXYGEN CONSUMPTION DURING SLEEP.

Experiments on oxygen consumption of man during sleep are confined to a few investigators. The criticism has been raised above that with the ordinary mouthpiece or nosepiece the experiments made during sleep must of necessity be considered as of a somewhat doubtful value, since with muscular relaxation there would be a liability to a leak around the mouth or nose. With the method of studying the respiratory exchange employed by Speck it would be impossible to make experiments on subjects lying asleep, although he emphasizes the importance of making experiments during sleep if possible.

Using the Zuntz-Geppert apparatus, Magnus-Levy, studying a man who had been fasting for some time, records a number of observations when the man was asleep.[1] From $9^h 45^m$ p. m. to $10^h 30^m$ p. m. the subject is reported as having been asleep, and the oxygen consumption during this time was 207.7 c. c. to 219.4 c. c., the average being 212.2 c. c. per minute. Again, from 1 a. m. to $1^h 41^m$ a. m. he was in part dozing and the oxygen consumption averaged 209.2 c. c. per minute. From $4^h 16^m$ a. m. to $4^h 40^m$ a. m., 2 experiments, when he was partly asleep, showed an oxygen consumption of 225.8 c. c.

Although direct statements as to the amount of sleep are lacking, in the experiments made by Laves[2] with the Hoppe-Seyler respiration chamber there were 2 experiments which were reported as having been made between 9 p. m. and 7 a. m., and it is highly probable that the subjects were asleep, although the sleep may not necessarily have been profound. The oxygen consumption during these two periods averaged 21.2 grams and 21.3 grams per hour, respectively.

In 1 experiment reported by Jaquet[3] in the original description of his apparatus, the subject was in the respiration chamber from 7 p. m. until 3 a. m., and it is highly probable that the values from 12 midnight until 3 a. m. were during sleep. The oxygen consumption during these 3 hours was 28.4, 27, and 23.7 grams, respectively.

Staehelin, using this same apparatus, made a number of experiments, all during the night. The results have been abstracted on page 178 of this report.

It is thus seen that there are but few experiments during sleep with which the results here presented can be properly compared. Since, however, we find such marked concordance between the results for the carbon-dioxide production obtained during the sleeping period with a large respiration chamber and the results obtained on subjects with complete muscular rest with the Zuntz-Geppert apparatus, it may be of interest to compare the results here obtained on sleeping man with those obtained on the resting man with complete muscular rest and 12 hours after the last meal. These results are given on page 156 of this report. By reference to this table it can be seen that the average oxygen consumption of the 19 subjects was 237 c. c. per minute, while with the subjects asleep, the average was 249 c. c. per minute. Per kilogram of body-weight per minute, the average of 19 subjects with the Zuntz-Geppert apparatus was 3.79 c. c. as against 3.75 c. c. with the sleeping subjects reported by us. The oxygen absorption per square meter of body-surface with the subjects with the Zuntz-Geppert apparatus was 121.7 c. c. as against 123 c. c. with the subjects asleep. The agreement is very striking in all the comparisons.

INFLUENCE OF PREVIOUS MUSCULAR ACTIVITY UPON OXYGEN CONSUMPTION DURING SLEEP.

In several of the experiments here reported, it is possible to study the oxygen absorption during sleep following different degrees of muscular activity, some-

[1] Magnus-Levy, Archiv f. die ges. Physiol., 1894, 55, p. 35.
[2] Laves, *loc. cit.*
[3] Jaquet, *loc. cit.*

what on the plan already discussed under the head of the carbon-dioxide production with similar conditions. These results are given in table 72. Under ordinary conditions, when sleeping after rest with food, B. F. D. absorbed 19.5 grams of oxygen per hour. Sleeping after severe muscular work, when the external muscular work amounted to the equivalent of about 420 calories, the oxygen absorption was 22.4 grams per hour. With A. L. L. the quantities after rest were 22.2 grams and after severe muscular work 23.9 grams, with a maximum of 27.3 grams per hour after severe muscular work extending from 8 a. m. to 3 a. m.

TABLE 72.—*Oxygen consumed during sleep (1 a. m. to 7 a. m.) following different conditions of activity.*

[Average per hour.]

Subject.	Sleep after rest.	Sleep after severe work.	Sleep after very severe work.
	Grams.	*Grams.*	*Grams.*
B. F. D.	19.5	[1]22.4	....
A. L. L.	22.2	[2]23.9	[3]27.3

[1] Heat equivalent of work done 420 calories.
[2] Heat equivalent of work done 450 to 460 calories.
[3] Heat equivalent of work done 957 calories. Period of sleep, 4 a. m. to 7 a. m.

Unfortunately, no experiments, aside from those made during short periods with the Zuntz-Geppert apparatus, throw much light upon the consumption of oxygen following severe muscular work. The results here reported would seem to imply that there was a distinct oxidation of material which continued for some time after the cessation of work, and therefore we are inclined to believe that the increased carbon dioxide noted was not due to a sweeping out of carbon dioxide previously formed, but that it was due primarily to increased metabolism resulting from the after-effect of the muscular work.

The influence of severe muscular work on the subsequent metabolism and the rôle that it plays in the process of recuperation after large drafts upon body-material are problems that would seem to justify extended investigation.

OXYGEN CONSUMPTION DURING WAKING HOURS.

The oxygen consumption has now been measured in the respiration calorimeter with 51 different subjects. Many of the experiments covered a considerable period of time and, indeed, with some subjects, were repeated several times. In others, the observations were confined to but 2 or 3 hours during 1 experiment. The results have been brought together in table 73, also arranged in order of the decreasing body-weight. Here, again, we deal with conditions of rest when the subjects are sitting quietly in the respiration chamber for the greater part of the time, and as may be expected, the results are somewhat greater than those found during sleep. The maximum oxygen absorption per

hour was found with the subject H. A., namely, 33.3 grams, and the smallest amount was found with the subject H. G., namely, 19.9 grams. The average of the results from all the subjects showed that 27.1 grams of oxygen were absorbed per hour by man when awake and at rest.

TABLE 73.—*Oxygen consumed during waking hours by different individuals in rest experiments.*

Subject.	Body-weight (without clothing).	Height.	Amount per hour.	Amount per minute.	Per kilogram of body-weight.		Per square meter of body-surface.[1]	
					Per hour.	Per minute.	Per hour.	Per minute.
	Kilos.	*cms.*	*Grams.*	*c. c.*	*Gram.*	*c. c.*	*Grams.*	*c. c.*
H. C. M.	86.3	166	30.7	358	0.355	4.14	12.7	148
W. O. A.	84.8	168	32.9	384	.388	4.53	13.8	162
F. G. B.	83.2	183	31.8	371	.382	4.47	13.5	158
D. W.	77.4	180	31.1	363	.403	4.70	13.9	163
G. G. R.	77.2	178	27.7	323	.359	4.12	12.4	145
S. C. D.	74.9	178	28.5	332	.380	4.42	13.0	152
W. R. L.	74.9	198	30.1	351	.402	4.67	13.7	160
W. E. D.	74.4	179	32.0	374	.430	5.01	14.7	171
F. C. B.	73.6	183	31.8	371	.433	5.26	14.7	172
H. C. K.	72.6	181	26.9	314	.372	4.34	12.6	147
H. F.	71.0	168	24.4	284	.343	4.00	11.5	135
A. L. L.	70.8	166	27.5	321	.388	4.52	13.0	152
R. D. M.	70.4	178	26.1	305	.371	4.30	12.4	144
J. R.	69.2	183	29.7	346	.429	5.00	14.3	166
N. M. P.	69.1	177	29.7	346	.429	5.01	14.3	167
A. M.	66.6	175	27.4	319	.411	4.80	13.5	158
B. F. D.	66.4	170	28.7	335	.432	5.04	14.2	166
C. R. Y.	66.4	170	28.3	331	.428	5.00	14.1	164
H. D. A.	66.2	181	32.6	380	.493	5.74	16.2	189
N. B.	66.0	172	22.8	266	.345	4.03	11.3	132
R. A. M.	65.0	166	28.7	335	.442	5.14	14.4	168
A. H. M.	64.3	179	23.5	275	.368	4.29	11.9	139
H. A. P.	64.3	180	24.1	281	.375	4.38	12.2	142
F. L. T.	64.3	192	31.9	372	.497	5.79	16.1	188
E. M. S.	64.3	175	24.7	288	.385	4.49	12.5	146
H. A.	64.1	170	33.3	389	.520	6.07	16.9	197
W. H. L.	63.2	174	26.3	306	.416	4.86	13.5	157
J. V. C.	63.2	173	27.1	316	.429	5.01	13.9	162
G. E. H.	63.2	179	20.4	238	.323	3.77	10.5	122
J. N. T.	63.1	173	29.6	346	.470	5.49	15.2	177
D. R. F.	62.4	173	24.4	285	.392	4.57	12.6	147
A. G.	62.3	170	28.2	329	.453	5.29	14.6	171
C. F. B.	62.2	170	30.7	358	.494	5.79	15.9	186
J. W. H.	60.9	175	32.3	377	.531	6.20	17.0	198
J. A. R.	59.2	180	23.2	271	.392	4.59	12.4	145
C. A. R.	59.0	174	25.4	296	.431	5.03	13.6	159
H. C. A.	58.9	172	24.5	286	.417	4.87	13.2	154
F. W. H.	58.4	173	25.5	298	.437	5.07	13.7	160
F. N. C.	57.6	168	27.1	316	.470	5.48	14.8	172
H. R. D.	57.5	171	22.4	261	.390	4.55	12.2	143
H. E. S.	57.2	178	25.0	292	.437	5.10	13.7	159
S. A. B.	56.4	166	24.3	283	.430	5.02	13.4	156
J. T. H.	56.0	170	25.6	298	.456	5.32	14.2	166
H. L. K.	55.6	166	26.3	307	.473	5.52	14.7	171
F. E. R.	52.2	168	22.6	263	.433	5.05	13.2	154
H. L. W.	51.8	164	24.2	282	.467	5.45	14.1	164
G. H. H.	51.7	163	26.7	312	.517	6.04	15.6	182
G. W. S.	51.5	173	23.2	271	.450	5.26	13.6	159
T. M. C.	50.5	166	23.8	277	.470	5.48	14.1	165
H. G.	49.2	160	19.9	232	.404	4.72	12.1	141
B. N.	46.4	168	24.6	288	.531	6.18	15.5	181
Average	....	....	27.1	316	.425	4.96	13.7	160

[1] In computing body-surface the formula of Meeh has been used: $12.312\sqrt[3]{\text{body-weight}}$.

Converting these values to cubic centimeters per minute we have a maximum of 389 c. c. and a minimum of 232 c. c. per minute. The average of all the subjects showed that 316 c. c. of oxygen were absorbed per minute.

Per kilogram of body-weight.—Computing the results on the basis of per kilogram of body-weight per hour, we find that the maximum oxygen consumption per hour was with the subjects B. N. and J. W. H., 0.531 gram, and the minimum 0.323 gram with the subject G. E. H. The average of all the experiments showed 0.425 gram of oxygen absorbed per kilogram of body-weight per hour. These figures correspond to 6.18 c. c. with B. N. and 6.20 c. c. with J. W. H., and 3.77 c. c. with G. E. H. The average of all the experiments showed 4.96 c. c. per kilogram of body-weight per minute.

Per square meter of body-surface.—Dividing the total amount per hour by the area of body-surface, computed by the formula of Meeh, we find that the absorption of oxygen per square meter of body-surface per hour varied from a maximum of 17 grams with the subject J. W. H. to 10.5 grams with G. E. H. The average of all the experiments showed 13.7 grams of oxygen absorbed per square meter of body-surface per hour.

The corresponding figures on the basis of cubic centimeters per minute showed a maximum of 198 c. c. with the subject J. W. H. and a minimum of 122 c. c. with the subject G. E. H. The average of all the experiments showed that there were 160 c. c. of oxygen absorbed per square meter of body-surface per minute.

The measurement of the oxygen absorbed by the body is of immense physiological value with reference to the energy production, and with regard to the apportionment of the katabolism between protein, fat, and carbohydrate. Subsequent discussion, in which the relation between the carbon-dioxide excretion, oxygen consumption, and the heat production is considered, will bring out these points more clearly.

RATIO OF OXYGEN CONSUMPTION DURING SLEEP TO THAT DURING WAKING HOURS.

As was seen by comparing the carbon-dioxide production during sleep to that in waking hours, there was a very considerable increase during the waking period over sleep, even although there was no measurable external muscular work performed. A comparison of the oxygen consumed during sleep with that consumed during waking hours at rest is presented in table 74, the

TABLE 74.—*Ratio of oxygen consumed during sleep to that consumed during waking hours in rest experiments.*

Subject.	(*a*) Amount per hour during sleep.	(*b*) Amount per hour during waking hours.	(*c*) Ratio sleeping to awake. (*b*+*a*)	Subject.	(*a*) Amount per hour during sleep.	(*b*) Amount per hour during waking hours.	(*c*) Ratio sleeping to awake. (*b*+*a*)
	Grams.	*Grams.*			*Grams.*	*Grams.*	
W. O. A.	21.2	32.9	100:155	H. A.	25.9	33.3	100:129
D. W.	24.2	31.1	129	A. H. M.	18.6	23.5	126
H. C. K.	21.9	26.9	123	S. A. B.	17.7	24.3	137
A. L. L.	23.1	27.5	119	H. R. D.	19.2	22.4	117
H. F.	19.9	24.4	123	H. E. S.	22.4	25.0	112
N. M. P.	21.7	29.7	137	H. L. K.	17.7	26.3	149
B. F. D.	20.1	28.7	143				
C. R. Y.	21.9	28.3	129	Average	21.1	27.5	100:130

ratios being given in the last column. The ratios vary from 100:112 with the subject H. E. S., to 100:155 with the subject W. O. A. On the average the ratio was 100:130, a ratio somewhat less than that found for the ratio between the carbon dioxide during sleep and during waking hours. The chief significance of the ratio is to indicate that the oxygen absorbed is considerably greater during waking hours than during the sleeping hours. The significance of the oxygen consumption when awake and when asleep must be left for discussion in another portion of this report.

CONCLUSIONS WITH REGARD TO OXYGEN CONSUMPTION.

As has been repeatedly implied in this discussion, the oxygen consumption *per se* has been directly determined on man too rarely to have as yet a great significance in the literature. The values obtained by the Zuntz-Geppert apparatus and by Speck during short experiments have been used to calculate the indirect calorimetry, and the results thus obtained have had to take the place of direct calorimetric measurements in much of the research in metabolism. With the advent of the direct measurement of heat by a respiration calorimeter, the necessity for the oxygen determination has not been felt so keenly, and in the large number of experiments made with the Middletown respiration calorimeter prior to 1905, the oxygen consumption was not directly measured. Subsequent to that date, with the modified type of apparatus all four factors of metabolism, namely, water-vapor elimination, carbon-dioxide production, oxygen absorption, and heat production have been simultaneously measured. With the heat production directly measured, the oxygen consumption has a special value as indicating the nature of the materials katabolized; by analyzing the urine and feces, and thus obtaining the total nitrogen excretion, it is possible to compute with considerable accuracy the katabolism during any given day and to apportion this katabolism among protein, fat, and carbohydrate.

This method enables us for the first time to obtain an idea in regard to the amount of carbohydrate, either in the diet or in body glycogen, which is consumed or katabolized during a given time. The direct oxygen determination, therefore, appears at the present time to be of the greatest value in indicating the amount of glycogen entering into the metabolism. Heretofore it has been necessary to assume that the carbon derived from material other than protein has been carbon of fat, but with both the oxygen consumption and the heat production directly measured, it is possible to apportion the katabolism with great accuracy. This has already been of considerable use in studying the fasting metabolism with man,[1] and it was there found that on the first day of inanition the body glycogen drawn upon for the katabolism may amount to 180 grams, and that on the second day of fasting there may likewise be a heavy draft upon glycogen.

[1] Benedict, *loc. cit.*

It is somewhat in the field of speculation to suggest the possibilities of the use of the direct measurement of oxygen for studying metabolism, but certainly, inasmuch as it renders possible a reasonably accurate study of the rôle that glycogen plays in katabolism, it has already proved of incalculable value in indicating to what extent diabetics can draw upon their already meager supply of glycogen. It is not out of the bounds of probabilities to state that the direct determination of oxygen in experiments of a pathological nature may throw an entirely new light upon the significance of the storage of glycogen in the body, the quantity of glycogen, and the rapidity with which this glycogen can be drawn upon to make up drafts upon body-material. Particularly is this the case in subjects where the storage of body glycogen is very low, as in diabetics.

HEAT ELIMINATION AND HEAT PRODUCTION.

METHODS AND APPARATUS FOR DETERMINING THE HEAT ELIMINATION.

The estimation of the total heat produced by man is possible in two ways. One method measures directly the heat radiated and conducted from the body-surface, making due allowance for the heat of vaporization of water from the lungs and skin, and for the changes in temperature of the body, as well as the sensible heat of excreta. The other method involves a study of the gaseous exchange from which are computed the kinds and amounts of materials katabolized. From the heats of combustion of these katabolized materials, and the well-known relationship between the energy of urine and the urinary nitrogen, an attempt is made to compute the energy transformations without the direct measurement, namely, by so-called "indirect calorimetry." It is impossible here, however, to enter into a detailed discussion of the relative merits and accuracy of these two methods. In the experiments here presented, we have the direct measurement of the energy transformations, and we do not depend in any way upon the chemical analyses of the expired gases. The results can, therefore, be considered from the standpoint of a physical experiment in which the energy liberated from the body in the form of heat and the energy required to vaporize the water leaving the lungs and skin may be measured directly.

An examination of the literature shows that calorimeters for use with man, particularly calorimeters that have been carefully calibrated and tested so as to prove their worth for accurate observations, are few in number. The calorimeters of the French investigators, including the emission calorimeter of Hirn,[1] have been of especial value in experiments where large amounts of heat are involved, as in experiments during muscular work. The use of the water-bath in which the temperature is raised by the heat production of the body has also made valuable contributions to the study of human calorimetry. Notwithstanding these facts, however, with the exception of the Pashutin[2] respiration calorimeter, which has been used so successfully by Likhatscheff, we know of no form of calorimeter suitable for experiments with man which has an accuracy approximating that of the respiration calorimeter developed originally in the chemical laboratory of Wesleyan University,[3] and with which the experiments reported in this memoir were made. Indeed, it appears from a careful examination of all the earlier recorded data that by reason of their incompleteness very few, if any, of the earlier experiments can be properly compared with the experiments made with the new apparatus, in which attention was given to the minutest detail with the view of studying with the greatest accuracy not only the heat elimination but likewise the heat production of man during a given experimental period.

[1] Hirn, Recherches sur l'equivalent mécanique de la chaleur, Paris, 1858.
[2] Likhatscheff, *loc. cit.*
[3] Atwater and Rosa, U. S. Dept. Agr., Office Expt. Stas. Bul. 63, 1899; Atwater and Benedict, Carnegie Institution of Washington Publication No. 42, 1905.

Some of the earlier forms of apparatus serve admirably for studying differences in the energy production of man, but for absolute measurements of the quantities involved the technique is, as a rule, open to grave criticism, and the absence of suitable controls is keenly felt when examining much of the older work. The more recently devised calorimeter of Dr. Letulle and Mademoiselle Pompilian[1] has unfortunately not been described with sufficient accuracy, nor have the test experiments made with it been published, so that we have very little conception of the present possibilities of this apparatus. Unfortunately, the original description of the Pashutin respiration calorimeter was in a dissertation in Russian, and hence inaccessible to most readers. With this apparatus, however, the control experiments seem to have been planned with unusual accuracy and forethought, and we have every reason to believe that the measurements made with it greatly exceed in accuracy those made by means of any previous apparatus.

While, therefore, it is possible to discuss the earlier literature with regard to both the vaporization of water and the carbon-dioxide production, and to a certain extent with regard to the oxygen consumption, it is practically impossible to compare the experiments here reported with any work made under similar conditions in an apparatus other than that devised by Pashutin and described in detail by Likhatscheff. In thus seemingly casting aside the work of many of the French investigators with the air calorimeter and the investigations with calorimeters designed to study the heat elimination from parts of the body, such as the arm and leg, we do not presume for a moment to belittle or to cast reflection upon the value of those experiments. The fullest acknowledgment should therefore be made to these investigators for the fundamental work done in thus blazing trails which were to be followed by subsequent workers with more fortunate means and appliances than were at the disposal of the pioneers.

The results of experiments with the Pashutin calorimeter as presented in the dissertation of Likhatscheff[2] show with 2 subjects at rest that one, A. D. P., 24 years old, and weighing 58 kilos, gave off in 3 experiments with food 80.5, 90.7, 82.2, and, when fasting, 74 calories per hour, respectively. With a second subject G. N. K., 24 years of age, weighing 65 kilos, the heat production per hour in two 24-hour experiments was 104.6 and 101.8 calories, respectively.

Likhatscheff and Avroroff,[3] when studying a woman patient, 17 years of age, weighing 51 kilos, and suffering with intermittent malarial fever, found as the average of 22 hours of observation on a day when no fever was present, a heat production of 67.3 calories. Although the experiment was made in 2-hour periods, and during several of the periods the subject slept soundly, there are

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[1] Letulle and Pompilian, Rev. de la Soc. Scientifique d'Hygiène Alimentaire, 1906, 3, p. 645.

[2] Likhatscheff, *loc. cit.*

[3] Likhatscheff and Avroroff, Reports of the Imperial Medical-Military Academy, St. Petersburg, 1902, 5 (Russian).

certain discrepancies in the results that make it impossible to accept the 2-hour figures for each experiment by itself. Thus, in the 4 successive 2-hour periods from 11 p. m. to 7 a. m., the heat production was 71.5, 65, 60.9, and 46.3 calories per hour, respectively, for each 2-hour period. For the period from 7 a. m. to 9 a. m., the heat production rose again to 69.4 calories. It is evident that the extremely low value observed in the period from 5 a. m. to 7 a. m. does not strictly represent the heat production during this time. While, therefore, the result for the 22 hours probably represents with considerable accuracy the true heat production of this subject, no very sharp distinction can be made between the hours when the subject was awake and when she was asleep, and, unfortunately, some of the results can not be used intelligently in discussing this relationship.

HEAT PRODUCTION AS COMPARED WITH HEAT ELIMINATION.

The measurement of the heat radiated and conducted from the surface of the body, the heat required to vaporize the water from the lungs and skin, and the sensible heat of excreta do not give by any means a true measurement of the heat production during a given period. There is a large reservoir of heat, as it were, in the body itself, and if there is a material change in body-temperature there is a material difference in the amount of heat stored in the body. If there is a rise in body-temperature, heat has been required to warm the body, and if there is a fall in temperature, some of the heat previously stored has been liberated. From the specific heat of the body and the weight of body-material, it is seen that the capacity of the body for storing heat is very great. It has been commonly assumed that the specific heat of the body is 0.83, and for a man of average body-weight, say 60 kilos, it can be seen that the hydrothermal equivalent of the body is practically 50 kilos. Consequently, if the body-temperature is increased 1°, this is equivalent to the storage of 50 calories of heat. A tenth of a degree change, which is relatively common, corresponds to 5 or 6 calories. Conversely, if the body-temperature falls, the equivalent amount of heat has been lost from the body, and measured by the apparatus, together with the heat produced during that period, and the measured heat is therefore greater than the heat produced by the amount of heat lost from the body in the process of cooling.

In experiments of 24 hours or more, these fluctuations in body-temperature do not play any considerable rôle. In experiments of 2 hours, or in subdividing 24-hour experiments into 2-hour periods, the true heat production measured for periods as short as 2 hours may be very considerably vitiated by neglecting to take into consideration changes in body-temperature and body-weight. We have, therefore, designated as heat elimination the heat as measured by the calorimeter and corrected for the heat of vaporization of water and sensible heat of excreta; and as heat production, the heat elimination corrected for changes in body-temperature and body-weight. As will be seen, the heat elim-

ination is by no means synonymous with heat production, and obviously in comparisons with the energy transformations computed from the gaseous exchange, we must use the total heat production rather than the heat elimination. In some of the earlier experiments, the necessity for this distinction was not so clearly brought out, and the temperature measurements are not as satisfactory as one could wish, particularly those temperature measurements taken with the clinical thermometer in the mouth or the axilla. With the introduction of the electrical-resistance thermometers, however, much more accurate body-temperature measurements can be made and continuously recorded.

It is important here, however, to point out that there is at present a possibility of error which may be very large, in the assumption necessitated by our present deficient knowledge with regard to the temperature changes of the body as a whole. At present we assume that any fluctuation of body-temperature observed when measuring the temperature deep in the rectum indicates a corresponding fluctuation in the average body-temperature of the whole body. This may or may not be true, and, as has been pointed out previously, it is highly desirable that a topographic study of body-temperature be made in order to indicate whether or not a change in temperature of 1° deep in the rectum is accompanied by a change in temperature of 1° in the axilla or mouth, or on the surface of the body.

EXPERIMENTS ON HEAT ELIMINATION AND HEAT PRODUCTION.

HEAT PRODUCTION DURING SLEEP.

In discussing the heat production of man, the same general plan followed in considering the carbon dioxide produced and oxygen absorbed will be adhered to here, namely, to first consider the heat production of individuals during sleep when the muscular activity is more nearly comparable in all cases. The heat production, or if no accurate records of body-temperature were available, the heat elimination was determined from 1 a. m. to 7 a. m. with 19 different subjects, varying in body-weight from 55 kilos to 84.7 kilos. With a few subjects but one experiment was obtained, but in most cases several periods were possible.

The results of experiments with 19 different subjects have been computed in so far as possible on the basis of heat production and placed in table 75. The values were all obtained during the period of 1 a.m. to 7 a.m., representing the subject in minimum muscular activity and during the greater part of the time in profound sleep. The body-weight and height for each subject are also given in the table. The heat production per hour varies from 56 calories in the case of the subject A. H. M. to 82.7 calories with the subject J. C. W. The average heat production for all the subjects was 70.9 calories. In order to compare the experiments more satisfactorily, they were computed on the basis of the heat production per kilogram of body-weight per hour, and the results vary from 0.86 calorie with the subject W. O. A. to 1.37 calories with the subject H. E. S. The average heat production per kilogram of body-

weight per hour during sleep for all the subjects was 1.07 calories. Basing the calculation on the area of body-surface we find that for every square meter of body-surface the average heat production per hour is 35.3 calories, ranging from 29.1 calories with A. H. M. to 42.7 calories with H. E. S.

In table 75 most of the results are of experiments in which the data permitted the computation of the heat production. In some instances only the data for the heat elimination were available. The results for the experiments here reported are in nearly all cases for sleep following rest rather than for work experiments. In a few instances, namely, with J. C. W., A. L. L., E. O., B. F. D., and J. F. S., the results likewise include the experiments made while

TABLE 75.—*Heat produced during sleep by different individuals (1 a. m. to 7 a. m.).*

Subject.	Body-weight (without clothing).	Height.	Heat production.			Subject.	Body-weight (without clothing).	Height.	Heat production.		
			Per hour.	Per kilogram of body-weight per hour.	Per square meter of body-surface[1] per hour.				Per hour.	Per kilogram of body-weight per hour.	Per square meter of body-surface[1] per hour.
	Kilos	*cm.*	*Cals.*	*Cals.*	*Cals.*		*Kilos*	*cm.*	*Cals.*	*Cals.*	*Cals.*
W. O. A.	84.7	168	72.8	0.86	30.7	H. A. ...	64.1	170	80.4	1.25	40.8
D. W. ..	78.3	180	81.5	1.04	36.1	J. F. S..	64.0	171	63.4	0.99	32.1
J. C. W.	77.2	178	82.7	1.07	37.1	A. H. M.	61.6	179	56.0	0.91	29.1
H. C. K.	72.0	181	74.9	1.04	35.2	S. A. B..	57.0	166	60.1	1.05	32.9
A. L. L.	71.3	166	80.7	1.13	38.1	H. R. D.	56.2	171	65.3	1.16	36.2
H. F. ...	71.0	168	67.1	0.94	31.8	H. E. S.	56.1	178	76.8	1.37	42.7
A. W. S.	69.4	176	69.2	1.00	33.3	F. E. S..	56.1	163	65.1	1.16	36.2
E. O. ...	68.3	173	70.5	1.02	34.3	H. L. K.	55.0	166	60.0	1.09	33.7
N. M. P.	66.9	177	75.7	1.14	37.3						
B. F. D.	66.4	170	71.9	1.08	35.6	Avge. .	....	...	70.9	1.07	35.3
C. R. Y.	66.1	170	73.6	1.12	36.6						

[1] In computing body-surface the formula of Meeh has been used: $12.312 \sqrt[3]{\text{body-weight}^2}$.

the subjects were sleeping after muscular work. If only the experiments in which sleep followed rest were included, the values would be somewhat less for these. For example, with B. F. D., who may be said to fairly represent the other subjects, the values for the amount of heat production per hour, per kilogram per hour, and per square meter of body-surface per hour would be 70, 1.05, 34.7 calories, respectively, values slightly lower than those given in the table.

INFLUENCE OF PREVIOUS MUSCULAR ACTIVITY ON HEAT PRODUCTION DURING SLEEP.

As was pointed out in the preceding paragraph, the influence of previous muscular activity tends to increase somewhat the heat production during sleep. Several of the experiments render possible a comparison of sleep after rest, sleep after moderate work, sleep after severe work, and, in one instance, sleep after very severe work, a comparison which has previously been made for the carbon-dioxide excretion and the oxygen consumption. The results are presented in table 76. Here again it is necessary at times to use values which involve only the heat elimination instead of the heat production. Since the results are the averages in most instances of a number of experiments, they represent with considerable accuracy the exact conditions and the differences are particularly well

defined. As may be seen from this table, the heat production during sleep is perceptibly increased by the preceding muscular activity, and within certain limits this increase is approximately proportional to the amount of the activity.

TABLE 76.—*Heat produced during sleep (1 a. m. to 7 a. m.). following different conditions of activity.*

[Average per hour.]

Subject.	Sleep after rest.	Sleep after moderate work.	Sleep after severe work.	Sleep after very severe work.
	Cals.	*Cals.*	*Cals.*	*Cals.*
E. O.	69.3	[1]74.8	....	....
J. F. S.	60.4	[2]65.3	....	....
J. C. W.	77.2	....	[3]83.1	....
B. F. D.	69.8	....	[4]83.3	....
A. L. L.	78.3	....	[5]83.7	[6]97.9

[1] Heat equivalent of work done 100 to 250 calories.
[2] Heat equivalent of work done 130 to 280 calories.
[3] Heat equivalent of work done 480 to 660 calories.
[4] Heat equivalent of work done 420 calories.
[5] Heat equivalent of work done 450 to 460 calories.
[6] Heat equivalent of work done 957 calories. Period of sleep, 4 a. m. to 7 a. m.

These results point again to a stimulated metabolism and indicate that there is an increased heat production accompanied by an increased katabolism as indicated by the increase in the carbon-dioxide excretion and oxygen absorption. While the difficulties pointed out previously in determining the heat production during short periods are ever present, it is clear that the problem of the influence of previous muscular activity upon heat production during sleep is of sufficient importance to warrant much further research.

HEAT PRODUCTION DURING WAKING HOURS IN REST EXPERIMENTS.

Direct measurements of the heat elimination or heat production were made in experiments with 55 different individuals; with some of the subjects but 1 experiment was made, but with the majority there were 2 or more. The experiments lasted from 3 hours to several days, and on the average the results obtained were for a period of from 6 to 8 hours' duration. The influence of extraneous muscular activity and minor muscular movements on the heat production has been too often emphasized to need further discussion here. Since these subjects were sitting up and not influenced by the enforced quiet of lying in bed, there were considerable differences in the muscular activity, although the subjects were not engaged in any extraneous muscular work and their movements were confined to those minor muscular movements possible for a man seated in a chair inside of a small respiration chamber. There was, however, by no means as complete muscular relaxation and enforced muscular quiet as that attending the experiments made in the laboratory of Zuntz and his associates. The results of the experiments here reported are more nearly comparable with the results obtained by Sondén and Tigerstedt in that these inves-

tigators allowed their patients to move about to a certain extent and did not enforce rigid muscular relaxation. Table 77 gives the results for our experiments arranged according to the body-weight of the subjects. The heat production per hour per individual varies from 75.8 calories with the subject H. R. D. to 112.5 calories with the subject J. N. T. The average for the 55 subjects is 97.1 calories per hour.

TABLE 77.—*Heat produced during waking hours by different individuals in rest experiments.*

Subject.	Body-weight (without clothing).	Height.	Heat produced.			Subject.	Body-weight (without clothing).	Height.	Heat produced.		
			Per hour.	Per kilo of body-weight per hour.	Per square meter of body-surface[1] per hour.				Per hour.	Per kilo of body-weight per hour.	Per square meter of body-surface[1] per hour.
	Kilos	*cm.*	*Cals.*	*Cals.*	*Cals.*		*Kilos*	*cm.*	*Cals.*	*Cals.*	*Cals.*
H. C. M.	86.3	166	109.3	1.27	45.4	J. F. S..	63.4	171	103.5	1.63	52.8
W. O. A.	84.8	168	110.8	1.31	46.6	W. H. L	63.2	174	92.0	1.46	47.2
F. G. B.	83.2	183	99.8	1.20	42.5	J. V. C..	63.2	173	104.3	1.65	53.5
D. W. ..	77.4	180	100.3	1.30	44.9	G. E. H.	63.2	179	84.8	1.34	43.5
G. G. R.	77.2	178	110.5	1.42	49.5	J. N. T..	63.1	173	112.5	1.79	57.7
J. C. W.	75.8	178	103.3	1.36	46.9	D. R. F.	62.4	173	89.3	1.43	46.1
S. C. D.	74.9	178	98.9	1.32	45.2	A. G. ...	62.3	170	100.0	1.61	51.8
W. R. L.	74.9	198	109.7	1.47	50.1	C. F. B..	62.2	170	110.0	1.77	57.0
W. E. D.	74.4	179	107.4	1.44	49.3	J. W. H.	60.9	175	111.1	1.83	58.3
F. C. B.	73.6	183	110.4	1.51	51.1	J. A. R.	59.2	180	89.2	1.51	47.8
H. C. K.	72.6	181	90.8	1.25	42.5	C. A. R.	59.0	174	94.7	1.61	50.8
H. F. ..	71.0	168	85.8	1.21	40.7	H. C. A.	58.9	172	91.3	1.55	49.0
A. L. L.	70.8	166	92.1	1.30	43.7	F. W. H	58.4	173	90.5	1.55	48.7
R. D. M.	70.4	178	92.7	1.32	43.9	F. N. C.	57.6	168	99.4	1.73	54.2
A. W. S.	69.4	177	110.7	1.60	53.2	H. R. D.	57.5	171	75.8	1.32	41.4
J. R. ...	69.2	183	104.3	1.51	59.1	H. E. S.	57.2	178	82.1	1.44	44.9
N. M. P.	69.1	177	108.0	1.56	52.0	S. A. B..	56.4	166	81.1	1.44	44.7
E. O. ...	68.4	173	104.9	1.54	51.0	J. T. H.	56.0	170	93.9	1.68	52.2
A. M. ...	66.9	175	106.8	1.60	52.7	H. L. K.	55.6	166	91.7	1.65	51.1
B. F. D.	66.4	170	101.8	1.53	50.4	F. E. R.	52.2	168	94.0	1.80	54.8
C. R. Y.	66.4	170	97.8	1.48	48.5	H. L. W	51.8	164	92.4	1.79	53.9
H. D. A.	66.2	181	108.5	1.64	54.0	G. H. H.	51.7	163	90.3	1.76	52.8
N. B. ...	66.0	172	92.3	1.40	45.9	G. W. S.	51.5	173	87.8	1.71	51.5
R. A. M.	65.0	166	99.0	1.53	49.7	T. M. C.	50.5	166	86.4	1.71	51.4
A. H. M.	64.3	179	83.4	1.30	42.2	H. G. ...	49.2	160	80.0	1.63	48.5
H. A. P.	64.3	180	85.1	1.32	43.1	B. N. ...	46.4	168	86.3	1.86	54.2
F. L. T.	64.3	192	106.4	1.66	53.7						
E. M. S.	64.3	175	103.2	1.61	52.3	Avge .	....	...	97.1	1.52	49.2
H. A. ...	64.1	170	92.0	1.44	46.7						

[1] In computing body-surface the formula of Meeh has been used: $12.312 \sqrt[3]{\text{body-weight}}$.

Computed on the basis of the heat production per kilogram of body-weight per hour we find that the maximum heat production was 1.86 calories with the subject B. N. and the minimum 1.20 calories with the subject F. G. B. The average of all the subjects was 1.52 calories per kilogram of body-weight per hour. Making the computations on the basis of the number of calories per square meter of body-surface per hour, we find that the minimum heat production was 40.7 calories with the subject H. F. and the maximum 58.3 calories with the subject J. W. H. The average of the results with 55 subjects shows that per square meter of body-surface there were produced 49.2 calories per hour. The variations exhibited in table 77 are no greater than one would naturally expect to find with so large a number of subjects differing in temperament and with different degrees of restlessness. Since the experiments were made at

various times during a period of several years and no particular attention was given to securing uniform muscular activity in all experiments, other than to approximate a minimum amount of muscular activity, it is seen that the variations are not great.

It is important to recognize that the experiments are not all strictly comparable, in that there were variations in the minor muscular activity. Furthermore, as has been pointed out previously, some of the experiments were made with a fasting subject and in some experiments food was eaten in varying amounts. The results as a whole give an average value which is probably fairly representative of the heat production of normal man.

RATIO OF HEAT PRODUCED DURING SLEEP TO HEAT PRODUCED DURING WAKING HOURS IN REST EXPERIMENTS.

With a number of the subjects it was possible to compare the heat production during the sleeping hours with that during the waking hours, a ratio that is of interest particularly when compared with the similar ratios for carbon dioxide, water, and oxygen, which have been given in preceding pages of this report. The results of this comparison between sleeping and waking hours are given in table 78, in the first column of which is recorded the heat production per hour

TABLE 78.—*Ratio of heat produced during sleep to that produced during waking hours in rest experiments.*

Subject.	(a) Amount per hour during sleep.	(b) Amount per hour during waking hours.	(c) Ratio sleeping to awake. ($b \div a$)	Subject.	(a) Amount per hour during sleep.	(b) Amount per hour during waking hours.	(c) Ratio sleeping to awake. ($b \div a$)
	Cals.	*Cals.*			*Cals.*	*Cals.*	
W. O. A.	72.8	110.8	100:152	C. R. Y.	73.6	97.8	100:133
D. W.	81.5	100.3	123	H. A.	80.4	92.0	114
J. C. W.	87.7	103.3	118	J. F. S.	63.4	103.5	163
H. C. K.	74.9	90.8	121	A. H. M.	56.0	83.4	149
A. L. L.	80.7	92.1	114	S. A. B.	60.1	81.1	135
H. F.	67.1	85.8	128	H. R. D.	65.3	75.8	116
A. W. S.	69.2	110.7	160	H. E. S.	76.8	82.1	107
E. O.	70.5	104.9	149	H. L. K.	60.0	91.7	153
N. M. P.	75.7	108.0	143				
B. F. D.	71.9	101.8	142	Average	71.5	95.3	100:134

during sleep, and in the second the heat production per hour during waking hours. Assuming the sleeping value to be 100, it is seen that the ratio of sleeping to awake varies from 100:107 with H. E. S., to 100:163 with J. F. S. The average of all the subjects shows that the ratio is 100:134. The comparison of the production of heat during sleep to that during work has not as great a value as might at first appear, particularly when we consider that there were many differences in the muscular activity of some of the subjects of these experiments. On the whole, however, the average of all the results would show that a fair comparison can be drawn between the heat production of the same subject when he was asleep, and during waking hours, when he was quietly

seated in a chair. The extraneous muscular activity is confined to moving somewhat in the chair, standing occasionally to go to the food aperture,—a movement that has received definite study,—(see page 61 of this report) and, during longer experiments, going to bed and rising. The minor muscular movements incidental to taking the food and dishes from the food aperture, and collecting the feces and urine, are likewise included. These minor muscular movements were of course made by many of the subjects and yet in practically all of the experiments reported in this table, the muscular operations during waking hours were for the most part comparable on different days and with different subjects. The only variation was in the taking of food, since some of the subjects partook of food and others did not. The influence of these special factors upon metabolism, however, is to receive special treatment in a subsequent portion of this report and need not be further dwelt upon here.

PROPORTION OF TOTAL HEAT ELIMINATION REQUIRED TO VAPORIZE WATER FROM LUNGS AND SKIN.

Heat may leave the body in several ways, by radiation and conduction from the surface, by warming the inspired air, by the heat of vaporization of water from the lungs and skin, and by the sensible heat of excreta. The measurements made with the respiration calorimeter and accessory apparatus permit the apportionment of the total heat elimination to certain of these various paths.

DURING SLEEP AND DURING WAKING HOURS IN REST EXPERIMENTS.

Inasmuch as the determination of the water vaporized from the lungs and skin is included in practically all experiments with the respiration calorimeter, one of the most prominent of these apportionments is the calculation of what part of the total heat output is required to vaporize this water. The subject has received considerable attention in the earlier publications from the chemical laboratory of Wesleyan University and in table 79 we have collected the results obtained on 17 subjects during sleep and during waking hours. For the most part the values are obtained directly from the heat elimination rather than from the heat production, for the proportion of the heat lost through the water vaporization bears a relationship not to the heat production but to the heat elimination. In a few instances, the heat production rather than the heat elimination is included, but in 24-hour experiments, or even in 6-hour experiments made under the conditions obtaining in these experiments, the heat elimination and heat production are usually almost identical, and it has not been deemed advisable to engage in a long calculation to separate carefully the experiments including the heat production from those in which only the heat elimination is given. For purposes of comparison, we believe it is reasonable to assume that the values are fairly indicative of the heat elimination. During sleep it can be seen that on the average 27 per cent of the total heat eliminated is required to vaporize the water from the lungs and skin. This percentage varies from 20 to

35 per cent. During waking hours with the same subjects the average proportion of the total heat required to vaporize the water from the lungs and skin is 21 per cent, noticeably lower than during sleep. The variations are from 19 to 26 per cent.

In table 79 only those subjects are used with which we have experiments both during sleep and during waking hours. As a matter of fact, we have experiments with 38 other subjects during waking hours which give an average of 24 per cent instead of 21 with the 17 here reported. The total 55 subjects, therefore, give an average of 23 per cent of the total heat as utilized to vaporize the water from the lungs and skin in waking hours.

TABLE 79.—*Proportion of total heat output used to vaporize water from the lungs and skin during sleep and during waking hours in rest experiments.*

Subject.	Proportion used during sleep.	Proportion used during waking hours.	Subject.	Proportion used during sleep.	Proportion used during waking hours.	Subject.	Proportion used during sleep.	Proportion used during waking hours.
	P. ct.	*P. ct.*		*P. ct.*	*P. ct.*		*P. ct.*	*P. ct.*
W. O. A....	28	19	E. O.	32	20	H. R. D...	24	20
D. W.	20	21	N. M. P....	23	21	H. E. S....	22	19
J. C. W....	26	21	B. F. D....	33	26	H. L. K....	28	22
H. C. K....	24	23	C. R. Y....	35	23			
A. L. L.....	28	22	J. F. S.....	30	20	Average .	27	21
H. F.	27	20	A. H. M...	27	20			
A. W. S....	28	19	S. A. B....	26	19			

Taking these 17 subjects and assuming 8 hours of sleep during the night it can be seen that the average per cent of heat required to vaporize the water from the lungs and skin during 24 hours would be 23 per cent.

In a lengthy series of experiments with fasting man it was found that 22 per cent of the total heat eliminated was absorbed in vaporizing water from the lungs and skin. An almost identical value was found in ten 24-hour experiments with food, namely, 22.1 per cent. Accordingly, it would appear that the figures here represent normal conditions and that we can state that during sleep man normally utilizes 27 per cent of the total heat production in vaporizing water from the lungs and skin, and during waking hours 21 per cent, the average of the 24 hours of sleep and awake being not far from 23 per cent.

DURING MUSCULAR WORK.

Although the primary object of this report is to consider the metabolism of normal man at rest and not during muscular work, it is advisable here to enter into a discussion bearing upon the influence of muscular work upon the proportion of the total heat required to vaporize the water from the lungs and skin, inasmuch as in at least two earlier publications the discussion has been based upon a somewhat erroneous foundation.

It is important in this discussion to note that so far as the measurement of total heat is concerned, it is a matter of indifference whether 1 gram of water is vaporized from the surface of the man's body, from his ordinary clothing, from

the bedding, or from the surface of the heat-absorbing system inside of the chamber. On the other hand, when we attempt to apportion the heat elimination between the heat of radiation and conduction, and the heat required to vaporize water from the lungs and skin, it is necessary to take into consideration not only the water vaporized and carried out of the chamber in the air-

TABLE 80.—*Proportions of total heat output used to vaporize water from the lungs and skin during different conditions of activity.*

[Averages of amounts for 24 hours.]

Subject.	During rest.				During moderate work.			
	(a) Heat elimination.	(b) Water vaporized from lungs and skin.	(c) Heat used to vaporize water. (b×0.586)	(d) Proportion of total heat used to vaporize water from lungs and skin. (c÷a)	(e) Heat elimination.	(f) Water vaporized from lungs and skin.	(g) Heat used to vaporize water. (f×0.586)	(h) Proportion of total heat used to vaporize water from lungs and skin. (g÷e)
	Cals.	*Grams.*	*Cals.*	*Per cent.*	*Cals.*	*Grams.*	*Cals.*	*Per cent.*
E. O.	2283	962	565	24.7	[2]3862	2242	1314	34.0
J. F. S......	2133	825	[1]488	22.9	[3]3544	1679	984	27.8
J. C. W.....	2397	881	[1]522	21.8	....	....	....	....
B. F. D.....	2213	960	[1]568	25.7	....	....	....	....
A. L. L.....	2304	950	559	24.3	....	....	....	....

Subject.	During severe work.				During very severe work.			
	(i) Heat elimination.	(j) Water vaporized from lungs and skin.	(k) Heat used to vaporize water. (j×0.586)	(l) Proportion of total heat used to vaporize water from lungs and skin. (k÷i)	(m) Heat elimination.	(n) Water vaporized from lungs and skin.	(o) Heat used to vaporize water. (n×0.586)	(p) Proportion of total heat used to vaporize water from lungs and skin. (o÷m)
	Cals.	*Grams.*	*Cals.*	*Per cent.*	*Cals.*	*Grams.*	*Cals.*	*Per cent.*
E. O.	....	....	....	....	....	....	....	....
J. F. S......	....	....	....	....	....	....	....	....
J. C. W.....	[4]5147	3339	1957	38.0	[7]9314	7381	4325	46.4
B. F. D.....	[5]4565	2870	1681	36.8	....	....	....	....
A. L. L.....	[6]4727	3547	2078	44.0	[8]7137	5940	3480	48.8

[1] Factor used, 0.592.
[2] Heat equivalent of work done 160 to 250 calories.
[3] Heat equivalent of work done 130 to 280 calories.
[4] Heat equivalent of work done 480 to 660 calories.
[5] Heat equivalent of work done 420 calories.
[6] Heat equivalent of work done 450 to 460 calories.
[7] Heat equivalent of work done 1482 calories. Rode ergometer till 7 a. m.
[8] Heat equivalent of work done 957 calories. Rode ergometer till 3 a. m.

current, but likewise to take into account the amount of water leaving the subject's body and condensed to a greater or less degree upon the surface of the heat-absorbing system. This requires not only analyses of the outgoing air to determine the amount of water-vapor leaving the chamber as such but likewise involves weighing the heat-absorbing system inside the chamber for the purpose

of noting the increase or decrease in the water condensed upon the pipes. In the form of apparatus used at Wesleyan University, provisions for these weighings were made and in practically all experiments, especially work experiments, the weights were taken. In the early reports, the importance of these weighings was overlooked and unfortunately computations were based only upon the water-vapor leaving the chamber as such, while as a matter of fact, a very large amount of water-vapor was distilled, so to speak, from the man's body upon the cold heat-absorbers; consequently, the proportion of total energy required to vaporize water from the lungs and skin was indicated as considerably less than was actually the case. In discussing here, therefore, the influence of muscular work upon the proportion of total heat required to vaporize water from the lungs and skin, we deal not only with water vaporized and leaving the chamber in the air-current, but the total water vaporized from the lungs and skin of the subject. Water may be carried out of the chamber in the air-current as water-vapor and during rest experiments is chiefly, if not wholly, withdrawn in this way, and yet the water vaporized from the body during work experiments is in large part condensed upon the cooling surface of the heat absorbers.

In the investigations here reported, with at least 5 subjects we have experiments showing conditions of varying muscular activity. With 3 of these, the muscular activity can be characterized as severe and very severe. In table 80 are recorded the total heat elimination, the water of respiration and perspiration, the heat used to vaporize water from the body, and finally the proportion of the total heat used to vaporize the water from the lungs and skin.

In the rest experiments in table 80 it is seen that the proportion of the total amount of heat used to vaporize water is substantially that ascribed to the 17 subjects in the preceding table, namely, 23 per cent. During moderate work, the heat equivalent of the external work done being from 130 to 280 calories, the proportion of total heat used to vaporize water increases to 27.8 and 34 per cent respectively. If the subject is engaged in severe muscular work—muscular work equivalent to 420 to 660 calories—the proportion of the total amount of heat used to vaporize water from the lungs and skin increases to approximately 40 per cent, and in 2 experiments where the subject was engaged in very severe muscular work equivalent to 957 to 1482 calories, with a total heat production amounting in one instance to 7137 calories in 24 hours and in the other to 9314 calories, the proportion of the total heat production required to vaporize water from the lungs and skin rises to 48 per cent. Thus, while in rest experiments but a small portion of the heat produced is required to vaporize water from the lungs and skin, as the muscular activity increases there is a very much larger proportion required and as the work increases, the most important factor in the increment is the heat absorbed as a result of the increased vaporization of water.

It is furthermore clear from this table that as the heat production increases as a result of muscular work, the increase is almost equally divided between

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the heat of conduction and radiation, and heat of vaporization of water. Thus, with the subject J. C. W., with severe muscular work, the total heat elimination was 5147 calories, of which 1957 calories were required to vaporize water or 38 per cent of the total. During very severe muscular work, the heat production increased to 9314 calories and the heat used to vaporize water was increased to 4325 calories so that of the increase of 4167 calories in the total heat production, considerably over 50 per cent or 2368 calories was required to vaporize water. Similarly, with the subject A. L. L., with severe muscular work the heat elimination was 4727 calories, of which 2078 calories were required to vaporize water. During the very severe muscular work, the total heat elimination increased to 7137 calories, of which 3480 calories were required to vaporize water; thus, in the increase from severe to the very severe muscular work the total heat elimination increased 2410 calories while the heat required to vaporize water increased 1402 calories or 58.2 per cent of the total heat elimination. It is obvious, therefore, that from 55 to 60 per cent of the increase in heat elimination resulting from increased muscular work leaves the body as latent heat of water vaporized from the lungs and skin. The important rôle that perspiration plays in the heat regulation is strikingly shown by experiments of this type.

ENERGY GIVEN OFF BY THE BODY IN DIFFERENT WAYS.

The preceding discussion with regard to the proportion of heat required to vaporize water from the lungs and skin during different conditions of muscular activity leads naturally to a discussion of the energy given off from the body in different ways. As has been pointed out previously, the paths for the excretion of heat during rest are by radiation and conduction and in the water vaporized from the lungs and skin, only a small amount being excreted in the form of urine and feces. During muscular work a fourth path, namely, the heat equivalent of external muscular work performed, is utilized.

As has already been pointed out, in the earlier publications an erroneous calculation was made in the amount of water vaporized, thus introducing an error into the calculation of the heat of vaporization of water. The results, therefore, are repeated here and given in table 81 for two reasons; first, to show the relative proportions of energy excreted in the various ways and, second, to give a permanent record of the correct values for experiments of this type. Furthermore, the experiments given in this table, both for rest and for work, are sufficient in number to show the characteristic differences in the apportionment of the total energy to the different paths during rest and during work. The table is copied exactly as given in the previous publication save that the correct calculations are made, basing the proportion of the water vaporized from the lungs and skin upon the total water of respiration and perspiration, rather than upon the water-vapor leaving the chamber.

From the average of the rest experiments, it is seen that 77.3 per cent of the total heat eliminated leaves the body by radiation and conduction, 0.7 per cent

TABLE 81.—*Energy given off by the body in different ways—Amounts per day and proportions of total eliminated in different ways.*

Subject and kind of experiment.	Days covered by experiments.	Quantities of energy per day.					Energy expressed in proportions of total.			
		Heat eliminated.					Heat eliminated.			
		(a) By radiation and conduction. $(e-(b+c+d))$	(b) In urine and feces.	(c) In water vaporized from lungs and skin.	(d) Heat equivalent of external muscular work.	(e) Total.	(f) By radiation and conduction. $(a \div e)$	(g) In urine and feces. $(b \div e)$	(h) In water vaporized from lungs and skin. $(c \div e)$	(i) Heat equivalent of external muscular work. $(d \div e)$
Rest experiments.		Cals.	Cals.	Cals.	Cals.	Cals.	P. ct.	P. ct.	P. ct.	P. ct.
Experiment No. 58, with H. F., carbohydrate diet	3	....	..	....	....	....	....	....	....	....
Maximum	..	1555	8	491	....	2047	....	....	....	....
Minimum	..	1347	8	300	....	1819	....	....	....	....
Average	..	1471	8	425	....	1904	77.3	0.4	22.3	....
Experiment No. 60, with B. F. D., carbohydrate diet	1	1623	22	568	....	2213	73.3	1.0	25.7	....
Experiment No. 65, with A. L. L., carbohydrate diet	1	1798	20	635	....	2453	73.3	0.8	25.9	....
Experiment No. 66, with A. L. L., carbohydrate diet	1	1929	19	523	....	2471	78.0	0.8	21.2	....
Experiment No. 67, with A. L. L., carbohydrate diet	2	....	..	....	....	....	....	....	....	....
Maximum	..	2178	24	520	....	2722	....	....	....	....
Minimum	..	2136	20	499	....	2655	....	....	....	....
Average	..	2157	22	510	....	2689	80.2	0.8	19.0	....
Rest experiments	8	....	..	....	....	....	....	....	....	....
Maximum	..	2178	24	635	....	2722	....	....	....	....
Minimum	..	1347	8	300	....	1819	....	....	....	....
Average	..	1760	16	502	....	2278	77.3	0.7	22.0	....
Work experiments.										
Experiment No. 56, with J. C. W., fat diet	3	....	..	....	....	....	....	....	....	....
Maximum	..	2505	29	2474	601	5433	....	....	....	....
Minimum	..	2253	20	2192	538	5124	....	....	....	....
Average	..	2365	23	2327	569	5284	44.8	0.4	44.0	10.8
Experiment No. 57, with J. C. W., carbohydrate diet	3	....	..	....	....	....	....	....	....	....
Maximum	..	2598	22	2481	657	5582	....	....	....	....
Minimum	..	2314	20	2305	563	5344	....	....	....	....
Average	..	2421	21	2391	602	5435	44.5	0.4	44.0	11.1
Experiment No. 61, with B. F. D., carbohydrate diet	1	2430	17	1699	419	4565	53.2	0.4	37.2	9.2
Experiment No. 62, with A. L. L., carbohydrate diet	3	....	..	....	....	....	....	....	....	....
Maximum	..	2603	15	2115	460	4852	....	....	....	....
Minimum	..	2262	12	1737	458	4802	....	....	....	....
Average	..	2391	13	1958	459	4821	49.6	0.3	40.6	9.5
Experiment No. 63, with A. L. L., fat diet	3	....	..	....	....	....	....	....	....	....
Maximum	..	2348	33	2340	460	4947	....	....	....	....
Minimum	..	2129	18	2060	458	4823	....	....	....	....
Average	..	2215	28	2188	459	4890	45.3	0.6	44.7	9.4
Experiment No. 64, with A. L. L., fat diet	1	2643	21	3516	957	7137	37.0	0.3	49.3	13.4
Work experiments	14	....	..	....	....	....	....	....	....	....
Maximum	..	2643	33	3516	957	7137	....	....	....	....
Minimum	..	2129	12	1699	419	4565	....	....	....	....
Average	..	2375	21	2272	546	5214	45.5	0.4	43.6	10.5

as the heat of urine and feces, and 22 per cent in the water vaporized from the lungs and skin. The 77.3 per cent apportioned to radiation and conduction may still further be subdivided, since it has been computed in previous experiments[1] that during rest, about 2 per cent of the total heat is required to warm the inspired air. Furthermore, an apportionment can be made of the water vaporized from the lungs and skin on the basis that of the 22 per cent of heat absorbed in vaporizing water, 9.8 per cent is from the lungs and 12.2 per cent from the skin. Consequently a more accurate apportionment would be 75.3 per cent as heat eliminated by radiation and conduction, 2 per cent required to warm the inspired air, 0.7 per cent for the heat of urine and feces, 9.8 per cent as heat of vaporization of water from the lungs and 12.2 per cent as heat of vaporization of water from the skin.

Considering the work experiments, we have a proportionately smaller amount as the sensible heat of excreta, urine and feces, and a larger amount in the water vaporized from the lungs and skin, while the fourth path, namely, the heat equivalent of muscular work, here plays an important rôle. The average of all the work experiments shows 45.5 per cent for radiation and conduction, 0.4 per cent for urine and feces, and 43.6 per cent for the water vaporized from the lungs and skin, and 10.5 per cent for the heat equivalent of external muscular work.

[1] Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 476.

RELATIONS BETWEEN THE VARIOUS FACTORS OF METABOLISM.

RELATION OF CARBON DIOXIDE ELIMINATED TO WATER VAPORIZED.

The relative ease with which carbon dioxide can be determined and the difficulties attending the determination of water make it highly desirable to find some relationship that may exist between the elimination of carbon dioxide and the vaporization of water. This ratio has been deemed of sufficient importance by some investigators to compute the values in a number of experiments. Since the same factors influence to a greater or less degree the elimination of both carbon dioxide and water-vapor, it is not unreasonable to expect that there may be a fairly constant ratio which will prove of value in computing the water elimination in an experiment where the carbon dioxide has actually been determined. Accordingly, the relationship between the carbon dioxide eliminated and the water vaporized under different conditions will next be considered.

TABLE 82.—*Ratio of carbon dioxide eliminated to water vaporized during sleep, after rest.*

Subject.	(a) Average carbon dioxide eliminated per hour.	(b) Average water vaporized per hour.	(c) Ratio $CO_2 : H_2O$. $(b \div a)$	Subject.	(a) Average carbon dioxide eliminated per hour.	(b) Average water vaporized per hour.	(c) Ratio $CO_2 : H_2O$. $(b \div a)$
	Grams.	*Grams.*			*Grams.*	*Grams.*	
W. O. A.	23.5	34.9	100:149	C. R. Y.	25.0	44.5	100:178
D. W.	26.6	27.7	104	J. F. S.	22.4	30.9	138
J. C. W.	25.1	36.2	144	A. H. M.	19.4	25.4	131
H. C. K.	24.8	30.3	122	H. R. D.	21.1	26.5	126
H. F.	22.4	30.9	138	S. A. B.	19.9	26.9	135
A. L. L.	24.0	37.0	154	H. E. S.	23.8	29.2	123
A. W. S.	24.0	33.5	140	H. L. K.	19.4	28.6	147
E. O.	22.6	38.1	169				
N. M. P.	24.6	29.9	122	Average ...	23.0	32.3	100:140
B. F. D.	23.0	38.9	169				

During sleep.—In the periods of most nearly uniform rest, namely, during sleep, we can compare with propriety the carbon-dioxide excretion with the water vaporized. These have been given in the case of 17 subjects in table 82. In order to make the figures more strictly comparable, only those values for carbon dioxide and water-vapor are here included which were obtained simultaneously, consequently the values for carbon dioxide may in a few instances appear somewhat at variance with the values given in other tables. A similar statement holds true with regard to the water vaporized per hour. In the last column is recorded the ratio of carbon dioxide to water, taking carbon dioxide as 100. It is seen that invariably there is more water vaporized per hour than carbon dioxide. This ratio may vary from 100 : 104 with the subject D. W., up to 100 : 178 with the subject C. R. Y. In general, for every 100 grams of carbon dioxide excreted there are 140 grams of water vaporized.

During waking hours.—A comparison of the carbon dioxide eliminated with the water vaporized has been made with 55 subjects in table 83. In order to make the comparison again a true one, the carbon dioxide produced and water

vaporized are compared only in periods where they were simultaneously determined. Consequently, in a few cases the figures per hour may not agree with the results presented in previous tables. In general, it is seen from an inspection of the figures that there is a larger amount of water-vapor than carbon dioxide excreted per hour. In a few instances, there is less water-vapor excreted than carbon dioxide, and the ratio, taking the carbon dioxide as 100, may vary from 100 : 91 with the subject H. C. A. up to 100 : 154 with the subject H. A. P. The average of all subjects shows that for every 33.1 grams of carbon dioxide produced there were 38.7 grams of water vaporized, the ratio being 100 : 117, a value considerably lower than that found during the night.

TABLE 83.—*Ratio of carbon dioxide eliminated to water vaporized during waking hours in rest experiments.*

Subject.	(a) Average carbon dioxide eliminated per hour.	(b) Average water vaporized per hour.	(c) Ratio $CO_2:H_2O$. $(b \div a)$	Subject.	(a) Average carbon dioxide eliminated per hour.	(b) Average water vaporized per hour.	(c) Ratio $CO_2:H_2O$. $(b \div a)$
	Grams.	*Grams.*			*Grams.*	*Grams.*	
H. C. M.	38.3	47.4	100:124	H. A.	34.3	45.3	100:132
W. O. A.	38.1	36.3	95	J. F. S.	36.0	35.6	99
F. G. B.	38.2	41.3	108	W. H. L.	34.7	42.0	121
D. W.	34.0	36.2	106	J. V. C.	33.2	43.6	131
G. G. R.	37.5	43.4	116	G. E. H.	26.8	33.5	125
J. C. W.	33.5	36.7	110	J. N. T.	38.8	40.5	104
S. C. D.	35.3	44.1	125	D. R. F.	33.3	32.5	98
W. R. L.	39.5	43.2	109	A. G.	35.0	40.5	116
W. E. D.	39.5	52.7	133	C. F. B.	35.9	39.3	109
F. C. B.	36.5	46.5	127	J. W. H.	39.6	46.7	118
H. C. K.	29.6	35.4	120	J. A. R.	30.9	31.9	103
H. F.	29.9	29.7	99	C. A. R.	32.4	38.6	119
A. L. L.	30.2	34.9	116	H. C. A.	32.4	29.6	91
R. D. M.	32.7	40.7	124	F. W. H.	31.2	43.4	139
A. W. S.	37.2	35.7	96	F. N. C.	33.9	34.7	102
J. R.	37.6	39.5	105	H. R. D.	25.9	25.7	99
N. M. P.	35.7	38.2	107	H. E. S.	27.4	27.3	100
E. O.	37.5	36.5	97	S. A. B.	26.2	26.7	102
A. M.	36.5	43.7	120	J. T. H.	29.6	38.4	130
B. F. D.	33.4	44.8	134	H. L. K.	31.3	34.9	112
C. R. Y.	33.9	38.0	112	F. E. R.	29.1	40.7	140
H. D. A.	34.3	44.1	129	H. L. W.	29.2	40.8	140
N. B.	29.0	39.7	137	G. H. H.	31.4	34.9	111
R. A. M.	34.8	47.7	137	G. W. S.	29.3	35.5	121
A. H. M.	26.9	29.0	108	T. M. C.	27.5	33.6	122
H. A. P.	30.2	46.5	154	H. G.	27.6	32.6	118
F. L. T.	37.0	42.0	114	B. N.	30.7	46.4	151
E. M. S.	32.5	39.9	123				
				Average	33.1	38.7	100:117

The variations in this ratio are easily explained by the fact that there was a much greater carbon-dioxide excretion in the day than during the night, while as has been pointed out in this report and in the report of a large number of experiments with men fasting, the water vaporized during the day period does not differ materially from that vaporized during the night. Consequently, a more or less constant water vaporization during the total 24 hours, when compared with a large carbon-dioxide excretion in one period of the day and a low excretion in another, would cause the marked variations in the ratios previously pointed out.

During 24 hours in rest experiments.—From the foregoing discussion it is seen that for every 100 grams of carbon dioxide excreted during the night with 17 subjects, there were 140 grams of water vaporized, while during the day with some 55 subjects, for every 33.1 grams of carbon dioxide excreted, there were 38.7 grams of water vaporized, or as 100 : 117. The difference between these ratios is so great that it is necessary to consider the quantities for 24 hours in order to have any adequate idea of the ratio of carbon dioxide eliminated to water vaporized during an experimental day of 24 hours' duration. With 17 subjects these comparisons have been made and are given in table 84, which shows the total excretion of carbon dioxide, the total water vaporized from the lungs and skin, and the ratios, taking the carbon-dioxide excretion as 100. This ratio varies from 100 : 103 with the subject H. R. D. to 100 : 135 with the subject B. F. D. The average of all experiments showed a ratio of 100 : 114.

TABLE 84.—*Ratio of carbon dioxide eliminated to water vaporized during 24 hours in rest experiments.*

Subject.	(a) Average carbon dioxide eliminated.	(b) Average water vaporized from lungs and skin.	(c) Ratio $CO_2 : H_2O$. $(b + a)$	Subject.	(a) Average carbon dioxide eliminated.	(b) Average water vaporized from lungs and skin.	(c) Ratio $CO_2 : H_2O$. $(b + a)$
	Grams.	*Grams.*			*Grams.*	*Grams.*	
W. O. A.	793	854	100:108	B. F. D.	721	971	100:135
D. W.	722	820	113	C. R. Y.	715	947	132
J. C. W.	741	872	118	J. F. S.	753	825	110
H. C. K.	670	736	110	A. H. M.	535	609	114
H. F.	659	726	110	H. R. D.	599	615	103
A. L. L.	720	880	122	S. A. B.	571	613	107
A. W. S.	789	853	108	H. E. S.	632	667	106
E. O.	799	962	120	H. L. K.	671	756	113
N. M. P.	697	776	111	Average	698	793	100:114

Under the conditions, then, obtaining in the respiration chamber, it is reasonably certain that for every 100 grams of carbon dioxide excreted during an experiment of 24 hours' duration there will be on the average 114 grams of water-vapor. Variations from this normal value are too great for one to assume this as a standard factor, and consequently for experiments where the water vaporized from the lungs and skin is desired, either for itself or to aid in computing the heat transformation, the results here shown will not permit of the calculation of the water vaporized from the determination of the carbon-dioxide excretion. Obviously, the results here may be affected by all those factors previously discussed which affect water-vapor excretion, such as the ingestion of food, muscular exercise, lying in bed awake or asleep, probably the temperature of the human body, the temperature of the environment, and likewise the relative humidity of the air.

Earlier investigations.—The earliest experiments that we have been able to find which permit of the comparison of the carbon-dioxide elimination and

water-vapor output are the series made by Pettenkofer and Voit[1] with the large respiration chamber at Munich. These experimenters determined the water vaporized, as well as the carbon dioxide exhaled, but more stress was laid upon the determination of carbon dioxide, and they recognized the possibility, indeed the probability, of a rather considerable error in the determination of water. However, the results as presented by them make possible certain calculations with regard to the ratio of carbon dioxide to water-vapor. In table 85 these ratios have been computed for the rest experiments. Considering the carbon dioxide as 100, the values in the table indicate the ratio for water.

TABLE 85.—*Ratio between carbon dioxide eliminated and water vaporized in experiments reported by Pettenkofer and Voit.*

[Carbon dioxide taken as 100.]

	Experiment Number.											
	I	II	III	V	VI	VII	X	XI	XII	XIII	XIV	XV
Day	104	...	122	65	99	85	120	108	111	130	111	118
Night	123	119	111	128	118	127	98	127	108	...	119	145
24 hours	112	...	117	91	107	103	111	116	110	...	115	130

Lewin[2] in 1881, making a series of experiments in the Pettenkofer respiration apparatus, determined both the carbon dioxide exhaled and water vaporized and the ratios found in 5 experiments during the night were as follows: 100:88, 120, 112, 112, and 116, respectively.

Using the Pashutin respiration apparatus, Sadovyen[3] in 1888 made a series of experiments in which both the carbon-dioxide elimination and water vaporized were determined.

In 3 experiments with a mixed diet the ratios were 100:178, 115, and 170, respectively. During a 2-day fast, 127 and 111 were found. In a 4-day fast, the ratios were 90, 89, 96, and 116, while with a non-nitrogenous diet containing only carbohydrates for 3 days the ratios were 163, 107, and 104. All the experiments were made with the same subject.

In their research on the total metabolism of different individuals, Sondén and Tigerstedt[4] determined the water-vapor in a number of experiments and they have computed the carbon-dioxide and water-vapor ratio for several of their subjects. The results are abbreviated in table 86.

Using the Pashutin respiration apparatus, Likhatscheff[5] reports 6 experiments with healthy subjects in which both the carbon-dioxide elimination and water vaporized were computed. The 24-hour ratios are as follows: 4 experi-

[1] Pettenkofer and Voit, Zeitschr. f. Biol., 1866, **2**, p. 459.
[2] Lewin, Zeitschr. f. Biol., 1881, **17**, p. 71.
[3] Sadovyen, *loc. cit.*
[4] Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 97.
[5] Likhatscheff, *loc. cit.*

ments with one subject gave 100 : 106, 106, 120, and 111, respectively; 2 experiments with a second subject gave 100 : 121 and 97, respectively.

Somewhat later Likhatscheff and Avroroff[1] found on a day "without fever" with a 17-year old girl, suffering from intermittent malarial fever, that the ratio of carbon dioxide eliminated to water vaporized in 24 hours was 100 : 124.

In a number of researches made with the respiration chamber in the Hygienic Institute in Berlin under Rubner's direction, both carbon-dioxide elimination and water vaporized have been determined. Many of the experiments were made at different temperatures and with marked variations in the relative humidity. Those of the experiments that are more strictly comparable with the conditions of the experiments presented in this report are given herewith.

TABLE 86.—*Ratio between carbon dioxide eliminated and water vaporized in experiments reported by Sondén and Tigerstedt.*

	Age.	No. of experiments.	Water per hour.	$CO_2 : H_2O$.
	Years.		*Grams.*	
Men	9.5 to 12.5	6	38	100:101
	13.5 17	4	45	100:103
	19.5 23	2	46	100:109
Women	8 13	5	33	100:133
	13 18	4	37	100:130
	60 70	1	37	100:140

Wolpert[2] recognizing the variations in the water vaporized dependent upon the temperature and relative humidity, calculated in rest experiments that the relationship of carbon-dioxide elimination to water vaporized was as 100 : 60 at a temperature of 17.3° C. and 61 per cent relative humidity; 100 : 100 at a temperature of 20.4° C. and a relative humidity of 20 per cent; and 100 : 215 at a temperature of 25.7° C. and a relative humidity of 26 per cent. During sleep he found 100 : 130 at 19° C. and 63 per cent relative humidity, and 100 : 230 at 21.1° C. and 23 per cent relative humidity.

With people representing 6 different trades, Wolpert found a relationship between carbon dioxide eliminated and water vaporized during rest as follows:

Woman shoemaker	100: 90	Draftsman	100 : 175
Writer	100 : 105	Lithographer	100 : 175
Tailor	100 : 170	Laundress	100 : 230

In experiments on himself at rest he found as an average 100 : 125. Laschtschenko[3] found with a subject weighing 71 kilograms at a temperature of 17° to 19° C. the ratios of 6 experiments were as 100 : 108, 97, 78, 106, 93, and 128.

Rubner[4] found with a subject weighing 71 kilos a ratio of carbon dioxide eliminated to water vaporized of 100 : 92. With a subject weighing 58 kilos, at a temperature of 15° to 25° C., an average ratio of 100 : 85 was found.

[1] Likhatscheff and Avroroff, *loc. cit.*
[2] Wolpert, Archiv f. Hygiene, 1896, **26**, p. 62.
[3] Laschtschenko, Archiv f. Hygiene, 1898, **33**, p. 148.
[4] Rubner, Archiv f. Hygiene, 1900, **38**, p. 133.

The possibilities of enormous variations in the ratio of carbon dioxide eliminated to water vaporized can be seen in the experiments made by Schattenfroh[1] who, working with the respiration chamber in Rubner's laboratory on a very fat man, weighing 95 kilos, found in 3 experiments at a temperature of 20° C. and a relative humidity of about 40 per cent, a ratio of carbon dioxide eliminated to water vaporized of 100:316. This enormous increase in the water vaporized from the skin of a fat man is a subject of considerable discussion by the author. The author considers the results are doubtful and uncertain. In contrast to these 3 experiments, there was a fourth made with a relative humidity of 65 per cent at a temperature of 20° C. where the ratio of carbon dioxide to water was 100:105, practically a normal value. In spite of this experiment, the author concludes that fat people give off about 60 per cent more water per square meter of body-surface than do thin people.

Staehelin,[2] working with the Jaquet respiration apparatus in Basel, so modified as to include the determination of moisture in the outcoming air-current, made a series of experiments during the night when he was quietly lying asleep. In some experiments after food and in another without food, both the carbon-dioxide elimination and water vaporized were determined and hence the ratios for carbon dioxide eliminated to water vaporized are easily computed. After 12 hours' fast he found 100:107; after mixed diet, 101; after fat diet, 103; after protein diet, 99; and after a protein and carbohydrate diet, 93.

Conclusions.—An examination of the ratios between the carbon-dioxide eliminated and water vaporized found in the experiments here reported and in those of other investigators leads directly to the conclusions recognized early by Wolpert, that relative humidity, temperature, and likewise the general physical condition of the subject may all play an important rôle in this relationship. The factor most profoundly affected is undoubtedly the water vaporized from the lungs and skin. It is seriously to be questioned if any relations that have hygienic or other scientific value can be found between the carbon-dioxide elimination and water vaporization, as this ratio is the resultant of a number of variables affecting each of the two factors.

RESPIRATORY QUOTIENT AND CALORIFIC EQUIVALENTS OF CARBON DIOXIDE AND OXYGEN.

Oxygen is taken out of the air into the lungs and there carried by the blood to different parts of the body where it takes part in the oxidation of body material and forms carbon dioxide, which is carried by the blood to the lungs and then escapes into the air. In the oxidation of this body material, the proportion of oxygen to carbon dioxide will, it is evident, depend considerably upon the nature of the material burned. Between the volume of the oxygen consumed and the volume of the carbon dioxide eliminated, there is a definite ratio depending upon the chemical nature of the material oxidized; consequently, the

[1] Schattenfroh, Archiv f. Hygiene, 1900, **38**, p. 108.
[2] Staehelin, Zeitschr. f. klin. Med., 1906, **66**, p. 201.

ratio between these two gases is of very considerable significance in interpreting the nature of the materials katabolized during an experiment with man.

From the chemical analysis of carbohydrate, it is seen that the hydrogen and oxygen of the molecule exist in the proportions to form water and in the oxidation of this material, the oxygen of the air is required only to oxidize the carbon, although this is far from stating that the oxidation proceeds in such a sharply defined direction that the carbon only is affected. The ultimate result is an oxidation of carbohydrate amounting to the oxidation of the carbon in the carbohydrate. It has been found that the volume of carbon dioxide resulting from the oxidation of carbohydrate is exactly equal to the volume of the oxygen absorbed.

On the other hand, since there is a relatively small amount of oxygen in the fat of food, there is not enough to oxidize the organic hydrogen in the molecule, and when the fat is burned in the body, oxygen is required not only to oxidize the carbon but also to oxidize a portion of the hydrogen. Here, again, it is not permissible to assume that the oxidation travels in any definite line or that the oxygen of the molecule has any selective function in combining with this or that hydrogen or carbon atom, but assuming that all the oxygen of the molecule is completely combined with the hydrogen, it can be seen from a computation of the molecular weights that the oxygen is still insufficient to completely oxidize the hydrogen of the molecule. Consequently, when oxygen is absorbed in the combustion of fat, it forms not only carbon dioxide but also a certain amount of water, and as a result, there is a larger volume of oxygen consumed than carbon dioxide produced, so that the ratio between the volumes of these two gases is very different when fat is oxidized.

Although, as has been pointed out in a number of previous discussions, the molecular rearrangements involved in the oxidation of carbohydrate or fat are comparatively simple, when we consider the oxidation of the complex protein molecule, the calculation and the problems of the oxidation are somewhat more difficult to trace. The oxidation of protein is very much complicated by the fact that the process of oxidation does not completely break down the protein molecule into carbon dioxide, water, and nitrogen. Indeed, there is a cleavage of the molecule in the body; the nitrogen is in large part excreted in the form of urea and allied compounds in the urine, and certain amounts of carbon, nitrogen, and hydrogen are also excreted unoxidized in the feces.

The calculation of the oxygen required to oxidize the remaining portion of the protein molecule has been made by a number of writers, but perhaps the clearest is that given by Loewy[1] in which he assumes that 100 grams of fat-free, dry substance of flesh contains 52.38 grams of carbon, 7.27 grams of hydrogen, 22.68 grams of oxygen, 16.65 grams of nitrogen and 1.02 grams of sulphur. Computing the amounts of the elements found in the urine and feces as a result

[1] Loewy, Oppenheimer's Handbuch der Biochemie des Menschen und der Tiere. Jena, 1908, 4, p. 156.

of this disintegration of the protein, Loewy computes the portion that is oxidized in the body as 41.5 grams of carbon, and 4.4 grams of hydrogen; the oxidation of these two materials requires 145.87 grams of oxygen. Of the 22.68 grams of oxygen in the 100 grams of flesh, 14.99 grams are excreted either in the urine or in the feces and thus only 7.69 grams enter into the oxidative processes; the remaining 138.18 grams of oxygen necessary for the oxidation must therefore be taken from the air. During the process of oxidation, 152.17 grams of carbon dioxide are formed. If these values are reduced to volume by the well-known formulas, the ratio, then, is as follows: $\frac{CO_2}{O_2} = \frac{77.39}{96.63} = 0.801$.

RESPIRATORY QUOTIENT AS AN INDEX TO THE CHARACTER OF THE METABOLISM.

Calculated Respiratory Quotients and Calorific Equivalents of Carbon Dioxide and Oxygen for Protein, Fat and Carbohydrate.

As an aid in interpreting the results of the experiments here reported and in the calculations of the ratios of the carbon dioxide and oxygen to the heat, the oxygen required to oxidize 1 gram of the various substances in the body material or food, the products of the oxidation of 1 gram of these substances, the relation of the volume of carbon dioxide eliminated and of oxygen absorbed, the number of calories per gram of carbon dioxide and the number of calories per gram of oxygen, *i. e.*, their calorific equivalents, have been computed and placed in table 87. For carbohydrate, we have selected starch, cane sugar and glucose; for fat, both animal fat and human fat are given, and fat-free, dry flesh represents the protein. While there are slight mathematical differences between the results presented in this table and those computed by other investigators, the values are substantially correct and may be taken as representing the average protein, fat and carbohydrate of either body material or food. The volumes of gases are reduced to standard conditions of barometer and pressure. The heat of combustion per gram is likewise given, and the respiratory quotient, namely, the relation between the volumes of carbon dioxide eliminated and the oxygen absorbed, is presented in the eighth column. Of especial significance in connection with the calorific equivalent of carbon dioxide, *i. e.*, the number of calories accompanying the formation of 1 gram of carbon dioxide, is the large difference between the values for carbohydrate and fat. On the other hand, the calorific equivalent of oxygen, *i. e.*, the number of calories accompanying the absorption of 1 gram of oxygen, is practically the same whether the material oxidized is carbohydrate, fat, or protein. The lowest value is for protein, but as has been frequently pointed out,[1] the protein rarely exceeds 15 per cent of the total energy transformation in a day. Consequently, the number of grams of oxygen, if correctly measured, should give an accurate index of the total energy transformation in an experimental period.

[1] See Magnus-Levy, Physiologie des Stoffwechsels, von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 1906, 2, p. 217.

TABLE 87.—*Respiratory quotients and the calorific equivalents of carbon dioxide and oxygen for protein, fats, and carbohydrates.*

Materials.	Oxygen required to oxidize 1 gram.		Products of the oxidation of 1 gram.				Respiratory quotient $\frac{CO_2 \text{ c. c.}}{O_2 \text{ c. c.}}$	Calorific equivalent of 1 gram.	
			Carbon dioxide.						
	Weight.	Volume.	Weight.	Volume.	Water.	Heat.		Of carbon dioxide produced.	Of oxygen required.
	Grams.	*c. c.*	*Grams.*	*c. c.*	*Grams.*	*Cals.*		*Cals.*	*Cals.*
Starch	1.185	829.5	1.629	829.3	0.556	4.20	1.000	2.58	3.55
Cane sugar...	1.122	785.4	1.543	785.5	.579	3.96	1.000	2.56	3.53
Glucose	1.066	746.2	1.466	746.2	.600	3.75	1.000	2.56	3.52
Animal fat...	2.876	2013.2	2.811	1431.1	1.065	9.50	.711	3.38	3.30
Human fat...	2.844	1990.8	2.790	1420.4	1.055	9.54	.713	3.42	3.36
Protein	1.367	956.9	1.520	773.8	.340	4.40	.809	2.90	3.22

If, therefore, the body were to burn pure carbohydrate, the volume of oxygen absorbed would equal exactly the volume of carbon dioxide eliminated. On the contrary, if the body burned pure fat, for every liter of oxygen absorbed there would be 710 c. c. of carbon dioxide expired, the remainder of the oxygen uniting with the organic hydrogen of the fat and appearing in the form of water. Similarly, if protein alone is burned, for every liter of oxygen absorbed there would be about 800 c. c. of carbon dioxide eliminated.

It is thus seen that we are able to approximate the nature of the material burned, if we know the relation between the carbon dioxide eliminated and the oxygen absorbed. If during an experiment it is found that the ratio of carbon dioxide to oxygen is 0.94, it is evident that the metabolism during this period must have been largely of a carbohydrate nature. If, on the contrary, as is frequently found in fasting experiments, the ratio of carbon dioxide to oxygen is 0.74, it is clear that the metabolized material must have been in large part fat. The relationship, then, between the carbon dioxide produced and the oxygen absorbed furnishes very valuable evidence as to the nature of the material katabolized, and if we know simultaneously the nitrogen excreted in the urine, the carbon dioxide eliminated and the oxygen consumed, we can apportion the total katabolism between the protein, fat, and carbohydrate.

It is unnecessary here to enter into an extended discussion as to the merits and accuracy of this method of apportioning the katabolism between the three principal body-constituents. For experiments of long duration, it seems clearly proved that a knowledge of the excretion of nitrogen in the urine, the carbon-dioxide elimination and oxygen consumption, and of the complete elementary analyses of the food and feces enables us to calculate the metabolism with very great accuracy and to apportion it between the protein, fat, and carbohydrate. While this may be true of long experiments, it is not, however, at present definitely proved with regard to short experiments. The assumption that the disintegration of protein is accompanied by an immediate excretion of nitrogen in the urine, and the oxidation of carbohydrate by an immediate absorption of an equivalent amount of oxygen is not definitely proved. There are many inter-

mediate steps between the absorption of oxygen and the excretion of carbon dioxide resulting from the oxidation of any material in the body. That these steps follow with lightning-like rapidity, one after the other, is hardly conceivable. On the other hand, it seems clearly proved that in an experiment lasting for 24 hours the delay in the excretion of carbon dioxide following the absorption of oxygen or the delay in the excretion of nitrogen following the katabolism of protein is either so uniformly timed at the beginning and end of each experiment as to compensate, or else the possible errors involved in assuming an immediate excretion are not greater than those involved in the determination of the total 24-hour amounts. Experiments are greatly needed for the comparison of indirect and direct calorimetry, namely, the determination of the katabolized materials for short periods and the control of these determinations by an estimation of the heat production during these periods, calculating from the katabolized materials the energy that they would produce when oxidized. By this means and this means only will it be possible for us to throw light upon the rapidity of oxidation and excretion of material and the coincidence in the production of heat, the absorption of oxygen, and the excretion of carbon dioxide.

Until this comparison has been made and definite results obtained, it is necessary, particularly in experiments of short duration, to interpret with some reserve the katabolism indicated by the respiratory quotient. In the experiments here reported, the nitrogen excretion in the urine was not determined for reasons previously stated;[1] consequently, it is not practicable for us to compute indirectly the katabolism and apportion it between the protein, fat, and carbohydrate, and from this apportionment of materials katabolized, compute the total heat production. The respiratory quotients were determined in most instances, and since the respiratory quotients have a general interest as indicating the nature of the material katabolized by man under ordinary conditions, they have been computed and are here presented.

RESPIRATORY QUOTIENTS IN METABOLISM EXPERIMENTS.

During sleep.—The difficulties incidental to determining the oxygen directly, especially in experiments of short duration, have already been pointed out. Unless the subject is under essentially the same conditions of muscular activity at the beginning and end of each period, the determinations of oxygen are liable to be vitiated. It is also necessary in order to determine the oxygen to know with considerable accuracy the exact temperature of the air inside of the respiration chamber. This temperature is determined by means of resistance thermometers whereby an average temperature is obtained. If the subject is lying covered with a blanket at the beginning of a period and is sitting in a chair at the end of the period, there are obviously very different thermometric conditions inside the chamber at the beginning and end of the period, and, as a result, there may be a considerable error in the exact measurement of oxygen. On the other hand, we find that the best conditions for measurements of temperature

[1] See p. 11.

and the determination of the oxygen are obtained during the period from 1 a. m. to 7 a. m., when the subject is asleep. We have, therefore, computed the respiratory quotients for a number of experiments made with subjects during the period from 1 a. m. to 7 a. m. and these are given in detail in table 88. The individual variations are quite marked, ranging from 0.67 with the subject A. H. M., November 14, to 1.01 with the subject S. A. B., January 28, 1905. It is highly probable that both of these figures are erroneous, for respiratory quotients below 0.7 or above 1.0 are rarely found in health. The average of all the experiments is 0.82. This then may be taken as indicating the average respiratory quotient of subjects at least 6 or 7 hours after the last meal. In a number of these experiments the sleeping period was, as a matter of fact, some 24 or 36 hours after the last meal, but usually the sleeping period was preceded by a meal at 6 p. m., or 7 hours before.

TABLE 88.—*Respiratory quotients of different individuals during sleep (1 a. m. to 7 a. m.).*

Subject.	Experiment No.	Date.	Respiratory quotient.	Subject.	Experiment No.	Date.	Respiratory quotient.
		1903				1905	
W. O. A..	102	Apr. 17	0.80	N. M. P..	Preliminary to 85	Dec. 9	0.89
		Apr. 18	.81		85	Dec. 10	.77
		1906				1903	
D. W. ...	Preliminary to 89	Jan. 10	.82	B. F. D..	Preliminary to 59	Dec. 18	.84
	89	Jan. 11	.78		59	Dec. 19	.78
		1903				1904	
J. C. W..	Preliminary to 56	Apr. 27	.84		Preliminary to 60	Jan. 27	.83
	56	Apr. 28	.77		60	Jan. 28	.85
		Apr. 29	.79			Jan. 29	.87
		Apr. 30	.81			Jan. 30	.83
	57	May 8	.85		61	Jan. 31	.83
		May 9	[1].94			1905	
		May 10	.93		104	May 6	.86
		1905		C. R. Y...		Mar. 30	.84
H. C. K..	Preliminary to 82	Nov. 24	[2].88		78	Sept. 14	.83
	82	Nov. 25	.82		Preliminary to 80	Oct. 27	[2].89
		1906			80	Oct. 28	.75
	154	May 16	.79	A. H. M..	135	Nov. 14	.67
	155	May 23	.79		Preliminary to 81	Nov. 21	.90
		1903			81	Nov. 22	.74
H. F.	Preliminary to 58	Nov. 10	.77	H. R. D..	Preliminary to 83	Dec. 5	.81
	58	Nov. 11	.86		83	Dec. 6	.77
		Nov. 12	.83			1906	
		Nov. 13	.81		151	May 18	.82
		1905				1905	
H. A.	143	Nov. 15	[3].77	S. A. B...	Preliminary to 71	Jan. 7	.90
		1904			71	Jan. 8	.75
A. L. L..	62	Apr. 17	.93		72	Jan. 12	.78
		Apr. 18	.84		Preliminary to 73	Jan. 28	1.01
		Apr. 19	.82		73	Jan. 29	.77
	63	Apr. 20	.78		74	Feb. 3	.77
		Apr. 21	.71			Feb. 4	.77
		Apr. 22	.76			Feb. 5	.73
	65	Apr. 24	.83		Preliminary to 75	Mar. 4	.90
	66	Apr. 25	.76		75	Mar. 5	.78
	67	Apr. 26	.86		76	Mar. 12	.78
		Apr. 27	.81			Mar. 13	.83
	68	Apr. 28	.78			Mar. 14	.91
	Preliminary to 69	Dec. 16	.78		Preliminary to 77	Apr. 8	.85
	69	Dec. 17	.76		77	Apr. 9	.79
	70	Dec. 21	.79	H. E. S..	79	Oct. 14	.77
		Dec. 22	.82	H. L. K..	Preliminary to 87	Dec. 13	.83
		1906			87	Dec. 14	.81
	Preliminary to 92	Mar. 6	.82			Dec. 15	.79
	92	Mar. 7	.85		88	Dec. 16	.78
		Mar. 8	.77			Dec. 17	.78
	93	Mar. 9	.86				
		Mar. 10	.81	Average			.82

[1] Period 4 to 7 a. m. [2] Period 1 to 5 a. m. [3] Period 1 to 3 a. m. and 5 to 7 a. m.

During waking hours.—With the necessarily greater unrest of subjects sitting in a chair, discrepancies in the determination of oxygen, which would ultimately vitiate to a certain extent the determination of the respiratory quotient, are frequently found. Many of the respiratory quotients, however, were determined with considerable accuracy and the results are reported in table 89. The variations are fully as great as in sleep and the table serves admirably to show that there may be wide variations in the respiratory quotient, not only between different individuals, but also with the same individual on different days. The average of all the experiments showed a respiratory quotient of 0.87. Since many of these experiments were made during the day and when full digestion was in process, it is fair to assume that the result indicates the average respiratory quotient during waking hours of the average man. This average value is considerably less than that commonly reported in text books, namely, 0.93. As has been pointed out frequently, however, the respiratory exchange is dependent in large part upon the character of the diet. If a diet containing a large quantity of carbohydrate is ingested, the respiratory quotient is high; if the diet contains a large amount of fat and is relatively low in carbohydrate, the respiratory quotient is low. Aside from indicating the general nature of the diet partaken of by man, the respiratory quotient as determined in experiments of this type has little, if any, value.

During period without food.—While the respiratory quotient extending over a 24-hour period has little or no value, owing to the varied nature of the diet partaken of by different individuals, the respiratory quotient determined 12 hours after the last meal has been used by many investigators as the base line for an extended series of investigations. It is thus assumed that 12 hours after the last meal when the stomach is empty and the effect of the previous diet is practically past, the subject is then living upon the protein, fat and carbohydrate of the body. The relative amounts of the materials oxidized depend in large part upon the previous storage of carbohydrate, chiefly glycogen of the body, and this is assumed to be a relatively constant amount for given individuals. The experiments here presented throw some light upon this subject and in table 90 the respiratory quotients have been computed, first, for the period from 1 a. m. to 7 a. m., and second, for a subsequent period at least 12 hours after the last meal is taken at 6 p. m. the night before. Theoretically one would expect to find almost invariably a noticeable diminution of the respiratory quotient as time progresses. This is clearly shown in 24-hour experiments with fasting man.[1] On the first day there is a heavy draft upon the body glycogen and the respiratory quotient is relatively high. On the second day, when the body glycogen has been considerably drawn upon so that the metabolism becomes chiefly that of fat, the respiratory quotient falls to not far from 0.74. In the experiments in table 90, the preliminary period shows, as a rule, a somewhat

[1] Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 451.

TABLE 89.—*Respiratory quotients of different individuals during waking hours in rest experiments.*

Subject.	Date.	Period.	Respiratory quotient
	1905		
H. C. M.	Apr. 27	9h 56m a.m. to 3h 56m p.m....	0.92
	June 9	9 53 a.m. 3 53 p.m....	.90
	1903		
W. O. A.	Apr. 17	7 00 a.m. 7 00 p.m....	.84
	1905		
F. G. B.	Oct. 23	5 46 p.m. 9 46 p.m....	.87
	1906		
D. W. ...	Jan. 10	7 00 a.m. 11 00 p.m....	.82
	Jan. 14	7 00 a.m. 1 00 p.m....	.78
	1905		
G. G. R..	Feb. 21	9 00 a.m. 12 00 a.m....	.95
S. C. D.	Apr. 28	9 16 a.m. 3 16 p.m....	.86
	June 21	9 17 a.m. 3 17 p.m....	.94
W. R. L.	May 2	10 28 a.m. 4 28 p.m....	.95
W. E. D.	June 14	9 22 a.m. 3 22 p.m....	.90
F. C. B..	Feb. 16	2 05 p.m. 5 53 p.m....	.78
	Mar. 22	2 21 p.m. 6 09 p.m....	.91
H. C. K.	Nov. 24	7 00 a.m. 11 00 p.m....	.80
	1906		
	May 3	9 05 a.m. 5 05 p.m....	.79
	1903		
H. F. ...	Nov. 10	7 00 a.m. 7 00 p.m....	.85
	Nov. 11	7 00 a.m. 7 00 p.m....	.85
	Nov. 12	7 00 a.m. 7 00 p.m....	.91
	1904		
A. L. L. .	Apr. 23	7 00 a.m. 10 00 p.m....	.79
	Apr. 24	7 00 a.m. 10 00 p.m....	.89
	Apr. 27	7 00 a.m. 10 00 p.m....	.79
	Dec. 16	7 00 a.m. 11 00 p.m....	.80
	Dec. 20	7 00 a.m. 11 00 p.m....	.76
	Dec. 21	7 00 a.m. 11 00 p.m....	.72
	1906		
	Feb. 9	9 00 a.m. 5 00 p.m....	.84
	Apr. 3	8 40 a.m. 12 40 p.m....	.82
	1905		
R. D. M.	May 12	8 48 a.m. 2 48 p.m....	.91
J. R. ...	May 11	9 00 a.m. 3 00 p.m....	.92
N. M. P.	Feb. 17	2 02 p.m. 5 02 p.m....	.90
	Feb. 27	2 00 p.m. 5 00 p.m....	.91
	Dec. 9	7 00 a.m. 11 00 p.m....	.81
A. M. ...	Mar. 1	1 48 p.m. 4 48 p.m....	.93
B. F. D.	Nov. 23	12 37 p.m. 3 02 32s p.m.	.78
	Dec. 18	7 00 a.m. 10 00 p.m....	.77
	1904		
	Mar. 3	7 00 a.m. 7 00 p.m....	.96
	Jan. 27	7 00 a.m. 10 00 p.m....	.89
	Jan. 28	7 00 a.m. 10 00 p.m....	.87
	Jan. 29	7 00 a.m. 10 00 p.m....	.93
	1905		
	May 6	7 00 a.m. 5 00 p.m....	.80
	May 31	2 28 p.m. 4 58 p.m....	.94
	June 2	2 44 p.m. 8 45 p.m....	.87
	June 3	12 45 p.m. 10 45 p.m....	.90
	1905		
C. R. Y.	Sept. 13	1 00 p.m. 7 00 p.m....	.91
	Sept. 14	7 00 a.m. 1 00 p.m....	.91
	Oct. 4	1 00 p.m. 7 00 p.m....	.87
	Oct. 27	7 00 a.m. 11 00 p.m....	.81
	1906		
	Feb. 8	9 15 a.m. 11 15 a.m....	.82
	1905		
H. D. A.	Feb. 8	3 33 p.m. 5 03 p.m....	.80
	Feb. 28	2 03 p.m. 5 03 p.m....	.82
N. B. ...	Jan. 23	10 59 a.m. 12 59 p.m....	.94
R. A. M.	June 8	9 24 a.m. 3 24 p.m....	.87
	June 13	9 42 a.m. 3 42 p.m....	.90
H. A. P.	June 12	9 44 a.m. 3 44 p.m....	.93
	June 20	9 10 a.m. 3 10 p.m....	.89
A. H. M.	Nov. 13	5 00 p.m. 11 00 p.m....	.78
	Nov. 14	7 00 a.m. 12 15 p.m....	.78
	Nov. 21	7 00 a.m. 11 00 p.m....	.75
	1906		
	Jan. 29	1 25 p.m. 4 25 p.m....	.94
	Jan. 31	12 45 p.m. 3 45 p.m....	.85
	Feb. 14	9 00 a.m. 5 00 p.m....	.85
	Apr. 2	2 57 p.m. 4 57 p.m....	.96
	Apr. 5	2 30 p.m. 4 30 p.m....	.78
	1905		
F. L. T.	May 1	9 23 a.m. 3 23 p.m....	.84
E. M. S.	Feb. 21	2 00 p.m. 5 00 p.m....	1.00
	Mar. 21	2 16 p.m. 5 16 p.m....	.91
H. A. ...	Nov. 14	3 00 p.m. 11 00 p.m....	.80
	Nov. 15	7 00 a.m. 11 00 a.m....	.70
W. H. L.	May 9	9 43 a.m. 3 43 p.m....	.96
	June 6	9 07 a.m. 3 07 p.m....	.96
J. V. C..	Feb. 10	9 01 a.m. 12 01 p.m....	.84
	Mar. 21	8 48 a.m. 11 48 a.m....	.96
G. E. H.	Feb. 17	10 35 a.m. 12 05 p.m....	.93
	Mar. 22	9 07 a.m. 12 07 p.m....	.92
J. N. T..	Feb. 15	2 01 p.m. 5 01 p.m....	.95
	Mar. 2	2 16 p.m. 5 16 p.m....	.95
D. R. F.	Feb. 15	10 34 a.m. 12 04 p.m....	.93
	Mar. 2	8 46 a.m. 11 46 a.m....	.97
A. G. ...	Feb. 18	2 07 p.m. 5 07 p.m....	.88
	Mar. 18	2 00 p.m. 5 00 p.m....	.92
C. F. B.	Jan. 18	1 40 p.m. 5 40 p.m....	.85
J. W. H.	Feb. 11	1 55 p.m. 4 55 p.m....	.88
	Mar. 23	1 40 p.m. 4 40 p.m....	.90
J. A. R..	Feb. 8	8 59 a.m. 11 59 a.m....	.95
	Feb. 28	9 15 a.m. 12 15 p.m....	.99
C. A. R.	Feb. 13	9 00 a.m. 10 30 a.m....	.96
	Mar. 18	8 57 a.m. 11 57 a.m....	.95
H. C. A.	Feb. 16	9 24 a.m. 12 24 p.m....	1.00
	Feb. 27	8 52 a.m. 11 52 a.m....	.92
F. W. H	May 10	9 13 a.m. 3 13 p.m....	.89
F. N. C.	Feb. 9	2 05 p.m. 5 05 p.m....	1.00
	Feb. 25	2 00 p.m. 3 30 p.m....	.82
H. R. D.	Dec. 5	7 00 a.m. 11 00 p.m....	.76
	1906		
	Feb. 10	9 15 a.m. 5 15 p.m....	.84
	Mar. 31	2 45 p.m. 4 45 p.m....	.95
	1905		
H. E. S.	Oct. 13	7 00 a.m. 11 00 p.m....	.80
S. A. B.	Jan. 7	7 00 a.m. 11 00 p.m....	.85
	Jan. 11	7 00 a.m. 11 00 p.m....	.73
	Jan. 28	7 00 a.m. 11 00 p.m....	.82
	Feb. 2	7 00 a.m. 11 00 p.m....	.73
	Feb. 3	7 00 a.m. 11 00 p.m....	.79
	Feb. 4	7 00 a.m. 11 00 p.m....	.77
	Mar. 4	7 00 a.m. 11 00 p.m....	.74
	Mar. 11	7 00 a.m. 11 00 p.m....	.75
	Mar. 12	7 00 a.m. 11 00 p.m....	.81
	Mar. 13	7 00 a.m. 11 00 p.m....	.85
	Apr. 8	7 00 a.m. 11 00 p.m....	.78
J. T. H.	Feb. 20	2 07 p.m. 5 09 23s p.m.	.84
H. L. K.	Feb. 20	8 59 a.m. 11 59 a.m....	.95
	Mar. 1	8 54 a.m. 11 54 a.m....	.89
	June 10	8 39 a.m. 2 39 p.m....	.85
	Dec. 13	7 00 a.m. 11 00 p.m....	.81
	Dec. 14	7 00 a.m. 11 00 p.m....	.84
	Dec. 15	7 00 a.m. 11 00 p.m....	.85
	Dec. 16	7 00 a.m. 11 00 p.m....	.87
F. E. R.	Feb. 11	9 01 a.m. 12 01 p.m....	.92
	Feb. 25	9 00 a.m. 12 00 noon...	.96
H. L. W	Feb. 4	2 02 p.m. 5 02 p.m....	.88
	Feb. 24	2 22 p.m. 5 22 p.m....	.88
G. H. H.	Feb. 14	9 23 a.m. 12 32 p.m....	.92
	Mar. 23	8 47 a.m. 11 56 a.m....	.80
G. W. S.	Feb. 18	8 59 a.m. 11 59 a.m....	.92
	Mar. 25	9 10 a.m. 12 10 p.m....	.91
T. M. C.	Feb. 13	2 06 p.m. 6 06 p.m....	.79
	June 7	9 04 a.m. 3 04 p.m....	.91
H. G. ...	Feb. 24	10 45 a.m. 12 15 p.m....	.94
B. N. ...	Apr. 29	9 44 a.m. 3 44 p.m....	.87
	June 5	10 22 a.m. 4 22 p.m....	.95
	June 15	10 30 a.m. 4 30 p.m....	.91
Miss S..	June 16	9 32 a.m. 12 02 p.m....	.95
	June 21	7 10 p.m. 9 40 p.m....	.93
Miss B..	June 22	9 18 a.m. 12 18 p.m....	.83
	June 23	8 54 a.m. 12 54 p.m....	.71
	June 24	9 02 a.m. 1 02 p.m....	1.00
Avge. ..	....	....	.87

higher respiratory quotient than during the following period, thus indicating that during this period, the influence of the preceding diet is still apparent. This is not invariably the case, however, and we have, therefore, to deal either with slight changes in the nature of the materials katabolized or possible errors in the determinations. As a rule, however, in experiments which are more or less continued, and in which the preliminary period is immediately followed or shortly followed by a period without food, the respiratory quotient is somewhat lowered as the fast progresses.

TABLE 90.—*Respiratory quotient during preliminary night (1 a.m. to 7 a.m.) and first hours of fast.*

Subject.	Date.	Period.	Character of period.	Respiratory quotient.
B. F. D.	Dec. 18, 1903	$1^h 00^m$ a.m. to $7^h 00^m$ a.m.	Preliminary	0.84
		10 00 a.m. 1 00 p.m.	Without food	.81
	May 6, 1905	1 00 a.m. 7 00 a.m.	Preliminary	.86
		9 00 a.m. 1 00 p.m.	Without food	.87
A. L. L.	Apr. 20, 1906	1 00 a.m. 7 00 a.m.	Preliminary	.84
		8 00 a.m. 12 00 noon	Without food	.80
	Dec. 16, 1904	1 00 a.m. 7 00 a.m.	Preliminary	.78
		9 00 a.m. 1 00 p.m.	Without food	.84
	Apr. 27, 1904	10 00 a.m. 1 00 p.m.	Do.	.85
	Feb. 9, 1906	9 00 a.m. 5 00 p.m.	Do.	.84
	Mar. 20, 1906	9 10 a.m. 5 10 p.m.	Do.	.84
	Apr. 3, 1906	8 40 a.m. 4 40 p.m.	Do.	.83
S. A. B.	Jan. 7, 1905	1 00 a.m. 7 00 a.m.	Preliminary	.90
		11 00 a.m. 1 00 p.m.	Without food	.87
	Jan. 28, 1905	1 00 a.m. 7 00 a.m.	Preliminary	1.01
		9 00 a.m. 1 00 p.m.	Without food	.88
	Mar. 4, 1905	1 00 a.m. 7 00 a.m.	Preliminary	.90
		9 00 a.m. 1 00 p.m.	Without food	.86
	Apr. 8, 1905	1 00 a.m. 7 00 a.m.	Preliminary	.85
		9 00 a.m. 1 00 p.m.	Without food	.78
C. R. Y.	Oct. 27, 1905	1 00 a.m. 5 00 a.m.	Preliminary	.89
		9 00 a.m. 1 00 p.m.	Without food	.92
A. H. M.	Nov. 21, 1905	1 00 a.m. 7 00 a.m.	Preliminary	.90
		9 00 a.m. 1 00 p.m.	Without food	.76
	Feb. 14, 1906	9 00 a.m. 5 00 p.m.	Do.	.85
	Mar. 26, 1906	8 35 a.m. 4 35 p.m.	Do.	.77
H. C. K.	Nov. 24, 1905	1 00 a.m. 7 00 a.m.	Preliminary	.88
		9 00 a.m. 1 00 p.m.	Without food	.83
	May 16, 1906[1]	1 10 a.m. 7 10 a.m.	Preliminary	.79
		9 10 a.m. 1 10 p.m.	Without food	.83
	May 23, 1906[1]	1 30 a.m. 7 30 a.m.	Preliminary	.79
		9 30 a.m. 1 30 p.m.	Without food	.85
	May 3, 1906	9 05 a.m. 5 05 p.m.	Do.	.79
H. R. D.	Dec. 5, 1905	1 00 a.m. 7 00 a.m.	Preliminary	.81
		9 00 a.m. 1 00 p.m.	Without food	.78
	May 18, 1906[1]	1 10 a.m. 7 10 a.m.	Preliminary	.82
		11 10 a.m. 1 10 p.m.	Without food	.85
	Feb. 10, 1906	9 15 a.m. 5 15 p.m.	Do.	.84
	Mar. 24, 1906	8 40 a.m. 2 40 p.m.	Do.	.76
N. M. P.	Dec. 9, 1905	1 00 a.m. 7 00 a.m.	Preliminary	.89
		9 00 a.m. 1 00 p.m.	Without food	.85
H. E. S.	Oct. 13, 1905	9 00 a.m. 1 00 p.m.	Do.	.86

[1] The subject had not eaten since about 9 a. m. on the preceding day.

An examination of table 90 shows that even 12 hours after the last meal, the respiratory quotient is not constant with the same individual. For example, with the first subject, B. F. D., in the experiment of December 18, 1903, the respiratory quotient from 10 a. m. to 1 p. m. was 0.81; in the experiment of May 6, 1905, from 9 a. m. to 1 p. m., the respiratory quotient was 0.87. With the subject H. R. D. in the experiments of May 18, February 10, and March 24, 1906, the values were 0.85, 0.84, and 0.76, respectively. Many other subjects

in the same table show a similar variation in the respiratory quotient even 12 hours after the last meal was taken.[1]

The respiratory quotient, therefore, as determined in experiments of this nature and in experiments in which the nitrogen excretion in the urine was not simultaneously determined, has only a general value as indicating approximately the nature of the material katabolized. Assuming an ordinary protein disintegration of about 100 grams a day, it would be possible to compute in a general way the relative amounts of carbohydrate and fat used, but as no direct determination was made of the nitrogen, this computation would have but little value.

Earlier investigations.—The respiratory quotient has been determined in innumerable cases by means of other forms of respiration apparatus in which a mouthpiece or nosepiece was used, and the hundreds of experiments of Speck[2] and of Zuntz[3] and his associates have all been made in such a manner as to give values for the respiratory quotient which are reasonably correct.

Respiratory quotients have been determined with man by the Zuntz-Geppert method under almost every conceivable condition of diet, muscular activity, and rest. While the apparatus is not adapted for the accurate determination of respiratory quotients during sleep, as it requires the strict attention of the subject[4] to hold the mouthpiece in position and insure absence of leaks, yet, since complete muscular relaxation is insisted upon by the best workers with this apparatus, the results obtained on trained subjects are distinctly comparable with the results obtained in our experiments during sleep, as has been pointed out previously. The respiratory quotient, when obtained under these conditions and combined with the determination of the nitrogen excretion in the urine, has been the basis of the methods of indirect calorimetry developed by Zuntz and his associates. Furthermore, while usually when exact results are desired, urinary analyses are made simultaneously with the determination of the respiratory exchange, it is quite common to determine the respiratory exchange and assume a relatively constant protein disintegration. The computation of the total katabolism and energy transformations by this method have received extensive treatment by Zuntz[5] and his co-workers. Since, in the experiments here reported, the energy transformations were directly measured, it is unnecessary to utilize the respiratory quotients for this purpose. On the other

[1] At the moment of writing an investigation is in progress in the Nutrition Laboratory of the Carnegie Institution of Washington at Boston, Mass., on the influence of the preceding diet upon the respiratory exchange 12 hours after the last meal. In this investigation very marked differences in the respiratory quotients are found, which depend upon whether the last meal of the preceding day consisted in large part of carbohydrates or was relatively poor in carbohydrates.

[2] Speck, Physiologie des menschlichen Athmens, Leipzig, 1892.

[3] See Loewy, Oppenheimer's Handbuch der Biochemie des Menschen und der Tiere. Jena, 1908, **4**, p. 179.

[4] See Rolly and Hörnig, Deutsch. Archiv f. klin. Med., 1909, **95**, p. 74.

[5] See Magnus-Levy, Pathologie des Stoffwechsels, von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 1906, **1**, p. 206.

hand, while it has been conclusively demonstrated that the indirect calorimetry in experiments of 24 hours' duration agrees perfectly with the direct calorimetry, we do not feel that the results obtained for 2-hour experiments are sufficiently accurate to warrant a comparison of the two methods, direct and indirect calorimetry. For such a purpose a special research is necessary, and, indeed, such a research is now in progress in the Nutrition Laboratory.

The results given in the tables in connection with this report are in such detail that it is perfectly possible and feasible to compute the indirect calorimetry, assuming in most instances, however, a relatively constant nitrogen excretion which has been found to be nearly the same with most individuals.

The respiratory quotient, then, has in this series of experiments no particular significance, other than to indicate in a general way the nature of the average diet of man under the conditions existing at the time these experiments were made. Apparently, therefore, the diet of the majority of the subjects contained relatively large amounts of fat with a relatively small proportion of carbohydrate. On the other hand, it must not be lost sight of that many of the experiments here included were made during the night when digestion had ceased and, indeed, some of them during the first day of fasting, and many 12 hours after the last meal, so that the tendency of a part of these experiments would be to distinctly lower the average respiratory quotients.

RELATION BETWEEN THE OXYGEN CONSUMPTION, THE CARBON-DIOXIDE ELIMINATION AND THE HEAT PRODUCTION.

In many of the earlier forms of respiration apparatus by which only the carbon-dioxide elimination could be determined, it was the custom to compute the energy transformations from the carbon-dioxide production, with due correction for the nitrogen in the urine. On this basis, it was assumed, after making due allowance for the carbohydrate in the diet, that the carbon not combined with the nitrogen in the form of katabolized protein was carbon of katabolized fat. In fasting experiments, the carbon unassigned to protein was invariably computed as carbon of fat, making no allowance whatever for the draft upon body glycogen. The error in this method of computation has been pointed out in a previous publication.[1] In experiments where mixed diets or diets of known character were administered, it was always assumed that the carbohydrate of the diet was first completely oxidized and then the remaining metabolism was ascribed to fat. While this method of computation certainly serves to indicate in a general way the total heat production in an experiment, obviously, factors founded on more substantial basis are highly desirable, and in a number of the experiments made with the apparatus at Wesleyan University, the relationships between the carbon dioxide produced and the heat eliminated have been carefully calculated. In certain of the experiments where the oxygen was determined, the relationship between the oxygen absorbed and the

[1] Benedict and Milner, U. S. Dept. Agr., Office Expt. Stas. Bul. 175, 1907, p. 213.

heat produced was likewise calculated. In previous publications these relationships have been designated as the "carbon-dioxide and oxygen thermal quotients," these terms indicating the number of grams of carbon dioxide or oxygen accompanying the production of 100 calories of heat. In this report the more explicit designation of "calorific equivalent" has been applied to the ratio between the amount of carbon dioxide and heat produced, and oxygen absorbed and heat produced.

A consideration of the chemical composition and the heat of combustion of many of the typical food materials shows that when protein is oxidized, for every gram of carbon dioxide produced, there are 2.90 calories of heat liberated, assuming the usual fragment of the protein molecule leaving the body in a partially-oxidized form. When fats are burned, for every gram of carbon dioxide produced there is a corresponding production of 3.42 calories of heat. When the carbohydrate glucose is oxidized, for every gram of carbon dioxide 2.56 calories are liberated, with cane sugar 2.56 calories, and with starch 2.58 calories. In general, the disintegration of sufficient carbohydrate to produce 1 gram of carbon dioxide results in a liberation of 2.57 calories of heat, with fat 3.42 calories, and for every gram of carbon dioxide produced when protein is oxidized we have a heat liberation of 2.90 calories.

The relationship between the carbon-dioxide elimination and the heat production depends in a large measure upon the nature of the material burned, and the absolute amount of carbon dioxide can not of itself indicate accurately the heat production, particularly when there are material changes in the nature of the diet or of the drafts upon body material. It may be assumed, however, that with an average mixed diet in which the proportions of carbohydrate and fat are relatively constant, the carbon dioxide can be taken as a reasonably accurate index of the total heat production, but if diets are consumed in which there is a marked preponderance of either fat or carbohydrate, the variations may be so great as to make the carbon-dioxide measurement of little or no value as an index of the heat-production. Obviously, in very few diets would the amount of protein be so large as to play an important rôle.

The marked difference in the chemical composition of carbohydrate and fat, more especially with regard to the proportion of oxygen in the molecule, account for the differences in the number of calories of heat liberated per gram of carbon dioxide produced, but if we examine the number of calories accompanying the absorption of 1 gram of oxygen, as given in table 87, we find that the differences are by no means as great. While there are wide differences in the amount of heat resulting from the disintegration of sufficient protein, fat, or carbohydrate to produce 1 gram of carbon dioxide, the calorific value of 1 gram of oxygen is much the same whether the oxygen is utilized in the combustion of protein, fat, or carbohydrate. The carbon-dioxide production may be taken as only an approximate index of the total energy transformation, but an exact knowledge of the oxygen consumption in an experimental period should give us a reason-

ably accurate method of computing the total energy transformation. Unfortunately the direct determination of oxygen requires apparatus fully as complicated and nearly as difficult to manipulate as does the direct determination of heat, and hence any relationship which may be established between the oxygen consumption and the heat production can be of but little aid to physiologists in general. These relationships are, however, of great importance in reviewing work in which the carbon dioxide, oxygen, and heat are simultaneously determined and in ascribing to errors in the determination of carbon dioxide, oxygen, or heat any discrepancies there found. This is clearly shown in a preceding publication,[1] where the carbon-dioxide thermal quotient and oxygen thermal quotient, *i. e.,* their calorific equivalents, were of incalculable value in indicating with great accuracy the exact nature of the error in one or two experiments, the results of which were otherwise inexplicable.

CALORIFIC EQUIVALENTS OF OXYGEN AND CARBON DIOXIDE IN METABOLISM EXPERIMENTS.

During sleep.—The difficulties attending the direct determination of oxygen in experiments of short periods have been frequently pointed out, and it is especially with experiments during sleep or during uniform muscular activity that the best results were obtained. The calorific equivalents of oxygen and carbon dioxide for a number of individuals during sleep are presented in table 91. Some of the results, namely, those with A. W. S., E. O., and J. F. S., are drawn from the experiments prior to the development of a method for the direct determination of oxygen and hence with these subjects, only the calorific equivalent of carbon dioxide can be given. The calorific equivalent of oxygen during sleep varies from 3.01 to 3.52, that is, for every gram of oxygen absorbed, there may be from 3.01 to 3.52 calories of energy liberated. On the average of all experiments, 3.37 calories of heat were produced for every gram of oxygen absorbed.

TABLE 91.—*Calorific equivalent of oxygen consumed and carbon dioxide eliminated for different individuals during sleep.*

Subject.	Calorific equivalent.		Subject.	Calorific equivalent.	
	Of oxygen.	Of carbon dioxide.		Of oxygen.	Of carbon dioxide.
	Cals.	*Cals.*		*Cals.*	*Cals.*
W. O. A.	3.44	3.10	C. R. Y.	3.36	2.94
D. W.	3.37	3.07	J. F. S.	....	2.83
J. C. W.	[1]3.47	[1]2.99	H. A.	3.11	2.92
H. C. K.	3.42	3.10	A. H. M.	3.01	2.89
H. F.	3.29	2.87	H. R. D.	3.40	3.10
A. L. L.	3.50	3.14	S. A. B.	3.39	3.02
A. W. S.	....	2.88	H. E. S.	3.42	3.23
E. O.	....	3.10	H. L. K.	3.39	3.10
N. M. P.	3.48	3.08			
B. F. D.	3.52	3.06	Average	3.37	3.02

[1] For 6 nights. The calorific equivalent of carbon dioxide for 61 nights was 3.13.

Examining the calorific equivalents of carbon dioxide, we find that they may vary from 2.83 to 3.23, the average being 3.02. In considering the calorific

[1] Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 513.

equivalent of carbon dioxide, it is necessary, of course, to bear in mind that the carbon-dioxide production varies widely with the nature of the material burned. With a carbohydrate-rich diet, therefore, where the storage of glycogen is probably somewhat above normal, even during the period from 1 a. m. to 7 a. m., or 6 to 7 hours after the last meal, there may still be an increased oxidation of carbohydrate, and while normally several hours after the last meal one would expect a subject to be living for the most part upon body fat, the results here show that there may be a not inconsiderable amount of carbohydrate burned during the sleeping period. The values in table 91 include all the experiments that can be collected with each of these individuals in which the same periods can be used to compute the calorific equivalents of both oxygen and carbon dioxide.

During waking hours.—While admittedly the determinations of the oxygen consumption during waking hours, especially with subjects not previously accustomed to the routine of an experiment, present certain difficulties by reason of the almost unavoidable differences in the muscular activity at the beginning and end of the period, nevertheless in a large number of experiments the oxygen consumption was determined simultaneously with the carbon-dioxide elimination and the heat production, and consequently we have computed and presented in table 92 the calorific equivalents of both oxygen and carbon dioxide for a large number of individuals during the waking hours. Included in this table are also those who appeared in table 91 for the carbon-dioxide and oxygen calorific equivalents during sleep. Many of the experiments continued for several days, but a large number of them were experiments of short duration, 4 to 8 hours. In certain of these experiments likewise, the calorific equivalent of oxygen could not be determined and only the calorific equivalent for carbon

TABLE 92.—*Calorific equivalents of oxygen consumed and carbon dioxide eliminated for different individuals during waking hours in rest experiments.*

Subject.	Calorific equivalent.		Subject.	Calorific equivalent.		Subject.	Calorific equivalent.	
	Of oxygen.	Of carbon dioxide.		Of oxygen.	Of carbon dioxide.		Of oxygen.	Of carbon dioxide.
	Cals.	*Cals.*		*Cals.*	*Cals.*		*Cals.*	*Cals.*
H. C. M.	3.56	2.86	B. F. D.	3.53	2.96	J. A. R.	3.85	2.89
W. O. A.	3.37	2.91	C. R. Y.	3.46	2.88	C. A. R.	4.03	3.07
F. G. B.	3.13	2.61	H. D. A.	3.33	2.99	H. C. A.	3.73	2.82
D. W.	3.23	2.95	N. B.	3.94	3.05	F. W. H.	3.55	2.90
G. G. R.	3.97	3.03	R. A. M.	3.45	2.84	F. N. C.	3.79	3.04
J. C. W.	....	3.09	A. H. M.	3.55	3.10	H. R. D.	3.38	2.92
S. C. D.	3.47	2.80	H. A. P.	3.53	2.82	H. E. S.	3.28	2.99
W. R. L.	3.65	2.78	F. L. T.	3.33	2.87	S. A. B.	3.33	3.10
W. E. D.	3.36	2.72	E. M. S.	4.18	3.17	J. T. H.	3.66	3.17
F. C. B.	3.47	3.02	H. A.	2.76	2.68	H. L. K.	3.48	2.93
H. C. K.	3.38	3.07	J. F. S.	....	2.87	F. E. R.	4.17	3.23
H. F.	3.52	2.94	W. H. L.	3.50	2.65	H. L. W.	3.82	3.16
A. L. L.	3.34	3.05	J. V. C.	3.85	3.14	G. H. H.	3.38	2.87
R. D. M.	3.55	2.83	G. E. H.	4.02	3.16	G. W. S.	3.79	2.99
A. W. S.	....	2.98	J. N. T.	3.80	2.90	T. M. C.	3.64	3.14
J. R.	3.51	2.78	D. R. F.	3.64	2.76	H. G.	3.89	3.01
N. M. P.	3.64	3.02	A. G.	3.55	2.86	B. N.	3.51	2.81
E. O.	....	2.80	C. F. B.	3.58	3.07			
A. M.	3.57	2.79	J. W. H.	3.44	2.81	Average	3.58	2.94

dioxide is reported. There are variations from 2.76 to 4.18 in the values for oxygen as may be seen by examining the table. The average of all the experiments showed 3.58 calories of heat liberated for every gram of oxygen absorbed, a value in all probability somewhat higher than normal since a diet of pure starch would require but 3.55 calories per gram of oxygen.

The indications are that the diets in these experiments were largely carbohydrate in nature, a conclusion at variance with the value found for the average respiratory quotient. The discrepancies can readily be assigned to difficulties attending the oxygen determinations in experiments as short as were the majority of the experiments from which the values in tables 73 and 89 were drawn.

The determinations of the carbon dioxide are not open to the error that is liable to occur in the determination of oxygen for short periods, and hence are on a more accurate analytical basis. The number of calories of heat accompanying the production of one gram of carbon dioxide varies widely, also, with different individuals, the highest being 3.23 with the subject F. E. R. and the lowest 2.61 with the subject F. G. B. The average of all the subjects showed 2.94 calories accompanying the production of 1 gram of carbon dioxide. These values are all within reasonable limits when compared with those given in table 87.

Comparison of calorific equivalents of oxygen and carbon dioxide during sleep, waking hours and for 24 hours.—A stricter comparison of the oxygen and carbon-dioxide calorific equivalents may be made when we consider those subjects that remained in the respiration chamber for not less than 24 hours. During this time there is a sleeping period, which is sharply characterized between 1 a. m. and 7 a. m., and a waking period from 7 a. m. to 10 or 11 p. m. We have also the data for the whole 24 hours. These results have been collected and presented in table 93 herewith. Furthermore, the results are so collected that the period of sleep follows immediately the period of waking hours in all cases, since there is the strictest comparison between the two. In so doing, certain of the values in the sleeping period may appear to vary from those previously recorded in table 91. Considering the calorific equivalent of oxygen, it can be seen that the average value during the waking hours from 7 a. m. to 10 or 11 p. m. is 3.34 calories; during sleep, 3.38 calories; and during the 24 hours, 3.37 calories. The calorific equivalent of carbon dioxide during waking hours is 2.97; during sleep, 3.08; and during the 24 hours, 3.00 calories. With regard to the calorific equivalent of oxygen it can be seen that the values are remarkably uniform for all subjects. Thus during the waking hours, the minimum is 3.22 calories and the maximum, 3.52 calories. Omitting the value for H. F., 3.52 calories, practically all the results are within 2 or 3 per cent of the average. During sleep the calorific equivalents ranged from 3.13 to 3.58 calories.

Of the greatest importance is the comparison of the oxygen calorific equivalent for different individuals for experiments of 24 hours' duration. During experiments of this length of time, most of the errors incidental to the determi-

nation of oxygen are eliminated, and consequently the results can be considered as satisfactory. The variations in the 24-hour experiments, therefore, are considered as well within the limits of the error of experimenting, the lowest value being 3.27 calories, and the highest, 3.48 calories. The variation above or below the average, 3.37 calories, is but about 3 per cent. It is evident, therefore, that in experiments of 24 hours' duration, where the oxygen consumption is accurately determined, the heat production of individuals subsisting on an ordinary mixed diet can be computed with an accuracy inside of 3 per cent.

TABLE 93.—*Calorific equivalents of oxygen consumed and carbon dioxide eliminated during sleep, during waking hours, and for total 24 hours in rest experiments.*

Subject.	Calorific equivalent of oxygen.			Calorific equivalent of carbon dioxide.		
	During waking hours.	During sleep.	During 24 hours.	During waking hours.	During sleep.	During 24 hours.
	Cals.	*Cals.*	*Cals.*	*Cals.*	*Cals.*	*Cals.*
W. O. A.	3.37	3.47	3.39	2.91	3.13	2.94
D. W.	3.29	3.31	3.33	2.93	3.10	2.98
J. C. W.	....	....	....	3.09	3.18	3.09
H. C. K.	3.28	3.58	3.34	2.97	3.17	2.99
H. F.	3.52	3.29	3.46	2.94	2.87	2.92
A. L. L.	3.31	3.48	3.37	3.04	3.22	3.10
A. W. S.	....	....	....	2.98	2.88	2.95
E. O.	....	....	....	2.80	3.07	2.86
N. M. P.	3.31	3.45	3.36	2.99	3.26	3.03
B. F. D.	3.41	3.53	3.48	2.86	3.10	2.92
C. R. Y.	3.39	3.18	3.38	2.84	2.93	2.90
J. F. S.	....	....	....	2.87	2.70	2.83
A. H. M.	3.41	3.13	3.34	3.29	3.07	3.24
H. R. D.	3.22	3.44	3.27	3.10	3.27	3.15
S. A. B.	3.33	3.32	3.34	3.10	3.09	3.08
H. E. S.	3.28	3.42	3.39	2.99	3.23	3.09
H. L. K.	3.29	3.33	3.36	2.84	3.08	2.91
Average	3.34	3.38	3.37	2.97	3.08	3.00

The calorific equivalent of carbon dioxide during the waking hours varied from 2.80 to 3.29 calories, averaging 2.97 calories. As is to be expected, with marked changes in diet or absence of food in certain cases, the fluctuations in the calorific output per gram of carbon dioxide would be larger than the corresponding fluctuations obtained on the measurements of the oxygen, and the values here reported may be considered as normal fluctuations. During sleep, the fluctuations vary from 2.70 to 3.27 calories, averaging 3.08 calories. The value 2.70 calories found for J. F. S. needs especial explanation. As has been pointed out in this table, the periods of sleep are taken immediately after the day period and do not represent all the periods of sleep with these different individuals, such as the sleep of the preliminary night. As a matter of fact, in the experiments with J. F. S., 12 experiments supplied the values from which the day value was drawn and the 12 following nights were used for the night period. Apparently with this subject there is normally a low carbon-dioxide calorific equivalent during the night, for in table 91 it is seen that this subject, J. F. S., showed a carbon-dioxide calorific equivalent of 2.83 calories, which was

the average of some 30 experiments. In table 91 the results from 12 days entered into the average, *i. e.*, 4 experiments of 3 days each. In these 4 experiments, the average carbon-dioxide production from 1 a. m. to 7 a. m. was 22.5, 21.5, 22.4, and 23.1 grams, respectively. The heat production during the corresponding period was 62, 60, 61, and 59 calories, respectively. The calorific equivalents of carbon dioxide in these 4 experiments were, then, 2.76, 2.79, 2.72, and 2.55 calories, respectively, the average being the low figure, 2.70 calories, reported in table 93. It is very much to be regretted that oxygen determinations were not simultaneously made in the experiments with this subject, but the experiments were all made prior to the completion of the method for determining oxygen.

The average carbon-dioxide calorific equivalent for the total 24 hours for all subjects is 3.00 calories, and this may be taken as a normal value for subjects at rest in the respiration calorimeter and subsisting on a mixed diet.

Conclusions.—From an examination of the results of the calorific equivalents of oxygen and carbon dioxide, the difficulties of calculating the heat production from measurements of either or both of these gaseous factors are apparent. While the simultaneous measurement of all three factors, carbon dioxide, oxygen, and heat, shows a uniform agreement between the energy of the material katabolized from the body as computed from the chemical transformation and the heat production during a 24-hour period, it is evident that using any one of these factors by itself, it is practically impossible to compute the heat production with an accuracy of less than 3 per cent. Of the two factors, by far the more accurate for this purpose, *i. e.*, showing the lesser variation from an average, is the oxygen consumption. Unfortunately, the determinations of the oxygen consumption present the greatest difficulties—difficulties that are, if anything, not exceeded by the difficulties attendant upon the direct measurement of the heat production.

RELATION OF EXTERNAL MUSCULAR WORK TO CARBON-DIOXIDE ELIMINATION, OXYGEN CONSUMPTION AND HEAT PRODUCTION.

Very few forms of muscular work permit of an accurate measurement of the calorific equivalent of the external muscular work performed. In experiments in which the subject walks up an inclined plane one has to deal not simply with the raising of the body to a given height, but likewise with the motion of forward progression. When the subject climbs a ladder, the work performed can be computed with considerable accuracy if the weight of the subject and the height to which the body was moved are known. In order to measure the external muscular work, such apparatus must be used as the brake ergometer, the handles of which can be moved by the arms, the ergometer of Zuntz,[1] the larger and more powerful machine devised by Johansson,[2] or a stationary

[1] Zuntz, Arch. f. Anat. u. Physiol., physiologische Abtheilung, 1899, p. 372.
[2] Johansson, Skand. Archiv f. Physiol., 1901, 11; p. 273.

bicycle, either so adjusted as to rotate a small electric machine and develop a current,[1] or in a more modified form with the electricity applied as a brake.[2]

With the close analogy between the human body and a machine, scientists have for many years attempted to compute or determine the mechanical efficiency of the human body, and these various types of ergometers have been used extensively for this purpose. With the apparatus of Zuntz or Johansson the mechanical work can be measured by noting the resistance of the brake on the weights raised, but the total output of heat by the body of the subject must be calculated indirectly from the respiratory gases. Both the carbon-dioxide exhalation and the oxygen absorption were measured in the Zuntz laboratory. With the apparatus of Johansson, on the other hand, the heat was not determined directly and only the carbon-dioxide elimination was accurately measured, no attempt being made to determine the oxygen consumption. From the factors obtained the total heat production was calculated by these investigators and the mechanical efficiency of the body as a machine was computed from the data.

Using an early type of bicycle ergometer, in which the rear wheel was made to rotate the armature of a small dynamo, a number of measurements were secured as to the mechanical efficiency of man in the respiration apparatus at Wesleyan University. Later, a more accurate machine was devised and utilized for this purpose, and the results have been reported by us elsewhere.[3] The measurement of the external mechanical work as performed on the earlier form of bicycle ergometer with the respiration calorimeter at Wesleyan University was subject to error, as the apparatus had not the accuracy or refinement that could be desired. On the other hand, the determinations of the carbon-dioxide elimination were made with the greatest accuracy, as were likewise the determinations of the heat production of the man himself. It was possible to calibrate the newer apparatus with great accuracy, and we believe that no measurements exist in which the external muscular work performed and the total heat production of man have been determined with as great accuracy. Consequently these experiments offer especially advantageous data for computing the mechanical efficiency of man. The computations for these investigations have been made and discussed in considerable detail in the publication previously referred to.

Carbon dioxide eliminated per kilogrammeter of work.—As has been stated, it is difficult to determine the amount of external muscular work performed in the carrying on of certain simple operations. On the other hand, if a reasonably accurate relationship can be established between the increment in the carbon-dioxide elimination above the resting value in experiments where the external muscular work can be accurately measured, then the carbon-dioxide increment can be used as a relatively accurate index of the external muscular

[1] Atwater and Benedict, U. S. Dept. Agr., Office Expt. Stas. Bul. 136, 1903.
[2] Benedict and Carpenter, *ibid.*, 208, 1909.
[3] Benedict and Carpenter, U. S. Dept. Agr., Office Expt. Stas. Bul. 208, 1909.

work performed in operations where the direct measurement is not practicable. While this report, therefore, does not deal primarily with experiments on muscular work, it is important here to point out that using the values obtained by means of the bicycle ergometer and a respiration calorimeter, and the values obtained with the brake ergometer or the ergostat of Johansson used in connection with the respiration chamber of Sondén and Tigerstedt, or the Zuntz-Geppert respiration apparatus, we should find certain relationships existing that may lead to generalizations of possibly considerable value in indicating the amount of external muscular work performed in experiments where the carbon-dioxide increment can be determined. By means of the large respiration chamber of Rubner in Berlin, or of the Sondén and Tigerstedt apparatus in Stockholm or Helsingfors, a number of household or commercial operations can readily be studied and the carbon-dioxide increment accurately determined.

In the report of the series of experiments carried out by Sondén and Tigerstedt, this problem has been discussed in considerable detail. In these experiments, two kinds of work were performed; in one the subject climbed up and down a ladder, in the other he rotated a brake ergometer. Since the increment in the carbon dioxide eliminated was accurately measured, the authors have computed the increment in the carbon-dioxide elimination per kilogrammeter of work performed. The authors also studied the increment in carbon-dioxide excretion which accompanied the moving of the body one pace in a horizontal direction. As a result of their experiments, they conclude that there is an increase in the carbon-dioxide elimination amounting to 0.000102 gram when 1 kilogram of body-weight is moved one pace in a horizontal direction. The average length of pace of the 4 subjects used was such that the average of all 4 subjects showed for every kilogram of body-weight moved 1 meter in a horizontal direction there was an increase in the carbon-dioxide elimination amounting to 0.000149 gram. The large size of the respiration chamber in Stockholm permitted an experiment of this kind.

Katzenstein,[1] working with the Zuntz-Geppert apparatus, also found a value for this factor, namely, the movement of 1 kilo of body-weight 1 meter in a horizontal direction. In 4 experiments the results averaged 0.000194 gram of carbon dioxide, an amount materially greater than that found with the Stockholm apparatus.

In computing the amount of work required to raise the body on a ladder, Sondén and Tigerstedt computed the height to which the body was moved and the number of times the ladder was climbed, but they neglected the work of going down the ladder. Neglecting this value, they found that for each kilogrammeter of work done there was an accompanying increase of carbon dioxide corresponding to 0.00428 gram. Katzenstein, when studying the work of ascending a mountain, found widely different results, the increase in the carbon-dioxide elimination being approximately one-half that reported from the Stock-

[1] Katzenstein, Archiv f. d. ges. Physiol., 1891, 49; p. 330.

holm laboratory. Sondén and Tigerstedt are inclined to consider Katzenstein's results as more accurate. Using an ergometer with 5 different subjects, the authors found for each kilogrammeter of work an increment in carbon dioxide of 0.003319 gram, which agrees quite closely with the value found by Katzenstein when using an ergometer, namely, 0.00317 gram. Making allowances for the work required to turn the ergostat without a load, the authors found that for each kilogrammeter of efficient work, the corresponding increase in the carbon dioxide was equal to 0.00368 gram.

Heinemann,[1] taking into account the variations in the carbon-dioxide elimination due to diet, made a series of experiments with the ergometer in which a fat diet, a carbohydrate diet, and a protein diet were given. The carbon-dioxide production per kilogrammeter of work on the ergometer was 1.445 c. c. with fat, 1.956 c. c. with carbohydrate, and 1.896 c. c. with protein. The average value found by Katzenstein and by Sondén and Tigerstedt with a mixed diet was 1.522 c. c. of carbon dioxide per kilogrammeter of work. Inasmuch as with an ordinary mixed diet there would be more carbohydrate than fat, the values found by Heinemann must be considered as somewhat larger than those found by Katzenstein or by Sondén and Tigerstedt.

The noticeable difference between the work experiments made by Sondén and Tigerstedt, by Katzenstein, and by Heinemann, and those made by us at Wesleyan University[2] is that in the former, the arms were used to rotate a brake-ergometer, while in the latter, the muscular activity was with the legs, which were used to rotate the wheel of a bicycle-ergometer. A comparison of the results found is, therefore, of unusual interest. In table 94 are recorded the increase in the carbon-dioxide elimination as a result of muscular work, the heat equivalent of the external muscular work expressed in terms of calories and again as kilogrammeters of work, and finally the increase of carbon dioxide per kilogrammeter and the kilogrammeters per gram of increase of carbon dioxide.

In a series of experiments with a professional bicycle-rider, N. B., the external muscular work in calories per hour varied from 59.9 to 115.7; the latter figure represented practically the limit of endurance and strength of the subject. The increase of carbon dioxide per kilogrammeter of work varied from 0.00363 to 0.00425 gram, averaging for the 6 experiments 0.00391 gram, these results being somewhat larger than those found by Sondén and Tigerstedt or by Katzenstein. For every gram increase of carbon dioxide, therefore, there was on the average 257 kilogrammeters of work done. There is certainly a remarkable agreement in results obtained by two such widely varying methods, one by using a brake ergometer moved by the arms, the carbon-dioxide elimination being determined in a large respiration chamber, and the other by using a special bicycle ergometer which had been carefully calibrated and the heat equivalent of muscular work very accurately measured, and yet the compared values are certainly within the limits of physiological error.

[1] Heinemann, Archiv f. d. ges. Physiologie, 1901, 83; p. 441.
[2] Benedict and Carpenter, U. S. Dept. Agr., Office Expt. Stas. Bul. 208, 1909.

TABLE 94.—*Carbon dioxide eliminated per kilogrammeter of work in experiments with N. B.*

[Amounts per hour.]

Date.	Current through magnet brake.	(a) Carbon dioxide above resting metabolism (grams).	(b) Heat equivalent of external muscular work (calories).	(c) Kilogrammeters of work. ($b \times 427$)	(d) Increase of carbon dioxide per kilogrammeter (gram). ($a \div c$)	(e) Kilogrammeters per gram of increase of carbon dioxide. ($c \div a$)
1904.						
October 21.....	1.25	186.7	104.5	44,622	0.00418	239
October 22.....	1.25	179.5	115.7	49,404	.00363	275
1905.						
January 23.....	1.25	191.3	114.2	48,763	.00392	255
January 24.....	.30	127.1	78.8	33,648	.00378	265
January 25.....	.80	102.9	65.4	27,926	.00368	271
January 26.....	.70	108.8	59.9	25,577	.00425	235
Average ...	....	....	....	....	.00391	257

In a series of experiments carried out in the Hygienic Institute in Berlin, Wolpert[1] showed that the carbon dioxide increased 1 gram for each 300 kilogrammeters of work, and thus each kilogrammeter of work[2] corresponded to 0.00333 gram of carbon dioxide. These results are somewhat lower than those in our experiments but fully in accord with those obtained by Katzenstein and by Sondén and Tigerstedt. Wolpert has made an interesting use of these figures in computing the external muscular work performed by individuals in various trades and occupations.

Oxygen consumed per kilogrammeter of work.—Although the greatest emphasis in these experiments was laid upon the determination of carbon-dioxide elimination, since practically all of these work experiments covered only 2 or 3 hours, we have nevertheless in some of them a reasonably accurate determination of oxygen. It is possible, therefore, to compute the increase of oxygen consumption per kilogrammeter of work and thus obtain a second factor which may also prove of value in interpreting the amount of external muscular work performed in certain experiments in which the oxygen increment can be readily determined. The results, which are given in table 95, are remarkably concordant, even more so than with the carbon-dioxide determination, since the increase in oxygen per kilogrammeter of work varied only from 0.00321 to 0.00353 gram, averaging, as a result of 4 experiments, 0.00342 gram. For every gram of oxygen increase above the resting metabolism there was, on the average, 293 kilogrammeters of work performed. The oxygen was not determined directly in the experiments of Sondén and Tigerstedt, but Katzenstein found for every kilogrammeter of work by means of the ergostat 1.957 c. c. of oxygen, corresponding to 0.00279 gram of oxygen, a value considerably lower than that found by us. Similarly, Heinemann found the values for oxygen per

[1] Wolpert, Archiv f. Hygiene, 1896, 26, p. 64.
[2] Wolpert states that a brake-ergometer was used. No description of the ergometer is given.

kilogrammeter of work on the ergometer to be, with a fat diet, 1.996 c. c.; with a carbohydrate diet, 2.172 c. c.; and with a protein diet, 2.377 c. c., or 0.00285, 0.00310, and 0.00339 grams, respectively. The corresponding respiratory quotients obtained at the time of these experiments were 0.722, 0.901, and 0.796. In our experiments with a professional bicycler, the respiratory quotients were in the 4 experiments in which oxygen was determined as follows: January 23, 0.90; January 24, 0.80; January 25, 0.80; and January 26, 0.90. It is seen, therefore, that the amount of oxygen per kilogrammeter in these experiments where the respiratory quotient was 0.85 is almost identical with that found by Heinemann in his experiments, with a respiratory quotient of 0.796.

TABLE 95.—*Oxygen consumed per kilogrammeter of work in experiments with N. B.*
[Amounts per hour.]

Date.	Current through magnet brake.	(a) Oxygen above resting metabolism (grams).	(b) Heat equivalent of external muscular work (calories).	(c) Kilogrammeters of work. (b × 427)	(d) Increase of oxygen per kilogrammeter (gram). (a ÷ c)	(e) Kilogrammeters per gram of increase of oxygen. (c ÷ a)
1905.						
January 23.....	1.25	156.3	114.2	48,763	0.00321	312
January 24.....	.90	118.7	78.8	33,648	.00353	283
January 25.....	.80	97.4	65.4	27,926	.00349	287
January 26.....	.70	88.3	59.9	25,577	.00345	290
Average ...	....	....	....	....	.00342	293

Heat produced per kilogrammeter of work.—In the experiments made with a bicycle-ergometer and a respiration calorimeter at Wesleyan University, it was possible to compute directly the kilogrammeters of work and the energy required per kilogrammeter of work thus performed. These values have been computed on a somewhat different basis in the publication of the original data, and table 96 shows the heat produced during work above that during rest, expressed in quantities per hour; the heat equivalent of external muscular work

TABLE 96.—*Heat produced per kilogrammeter of work in experiments with N. B.*
[Amounts per hour.]

Date.	Current through magnet brake.	(a) Heat above resting metabolism (calories).	(b) Heat equivalent of external muscular work (calories).	(c) Kilogrammeters of work. (b × 427)	(d) Increase of heat per kilogrammeter (calorie). (a ÷ c)	(e) Kilogrammeters per calorie of increase of heat. (c ÷ a)
1904.						
October 21.....	1.25	531.2	104.5	44,622	0.01190	84.0
October 22.....	1.25	522.0	115.7	49,404	.01057	94.6
1905.						
January 23.....	1.25	527.2	114.2	48,763	.01081	92.5
January 24.....	.90	381.1	78.8	33,648	.01133	88.3
January 25.....	.80	311.2	65.4	27,926	.01114	89.7
January 26.....	.70	292.7	59.9	25,577	.01144	87.4
Average ...	....	....	....	....	.01120	89.4

expressed as calories and as kilogrammeters; and finally, the increase of heat per kilogrammeter, and the number of kilogrammeters of work performed per increase of each calorie of heat. The results of the 6 experiments show a practical uniformity. Thus, for every kilogrammeter of work performed there was an increase in the heat production above the resting metabolism of 0.0112 calorie, the variations ranging from 0.01057 to 0.01190 calorie. For every increase of 1 calorie above the resting metabolism, there were on the average 89.4 kilogrammeters of work performed, the amount ranging from 84.0 to 94.6 kilogrammeters. Thus, since one calorie is equivalent to 427 kilogrammeters, it can be seen that the mechanical efficiency of the body may be obtained by the formula $89.4 \times 100 \div 427 = 20.9$ per cent.

VARIATIONS IN METABOLISM DUE TO VARIATIONS IN PHYSICAL CHARACTERISTICS, AGE AND MUSCULAR ACTIVITY.

VARIATIONS IN METABOLISM DUE TO WEIGHT, HEIGHT AND AGE.

As early as the investigations of Andral and Gavarret,[1] the differences in metabolism of individuals with marked variations in body characteristics, especially in regard to size, weight, height, and age, were considered possible. The most extended investigations of this kind are those of Sondén and Tigerstedt[2] with the large respiration chamber in Stockholm, and those of Magnus-Levy and Falk[3] with the Zuntz apparatus. These two investigations, primarily undertaken with the idea of studying the effect on metabolism of variations in age and sex, must still remain as our basis for these comparisons, but in the experiments made with the respiration calorimeter and published in this and previous reports, certain further evidence is at hand for studying the influence of variations in body condition on metabolism. No general investigation with this particular point in view was undertaken, but the experiments as selected from the list of 55 men experimented with enable us to make certain comparisons and deductions.

One of the first difficulties experienced is the proper classification of the men and the application of some popular term that will give a general idea as to the physical condition of these individuals. In certain cases the distinction between the men is very marked; thus with the professional athlete, N. B., there is no question that there was very little, if any, superfluous fat. On the other hand, the subject, H. F., although of distinctly athletic proportions and build, and a man of wonderful strength, nevertheless had a distinct layer of abdominal fat that would exclude him from being classified as an athlete, and from the body-weight and height we class him herewith among the short, fat men. The subject A. L. L., however, with identically the same body-weight as H. F., and, indeed, even less in height, is grouped as a short man, for a physical examination of this subject showed very little superfluous fat and he was distinctly of the athletic type.

It is evident that a classification involving so much personal opinion and judgment can be considered as only approximate and it is at best distinctly unsatisfactory. Until some uniform method is adopted of expressing body-weight and body measurements in such a way as will classify them in well-defined groups, we have no other alternative than to be strongly guided by personal impression. The possibility has been considered of photographing the body in profile in two positions at right angles to each other, but the investigation did not seem to warrant making such elaborate attempts to describe the body condition; indeed, it would now be impossible to secure accurate data, since a number of these subjects had not reached maturity at the time of the

[1] Andral and Gavarret, *loc. cit.*
[2] Sondén and Tigerstedt, *loc. cit.*
[3] Magnus-Levy and Falk, *loc. cit.*

experiments and consequently the body-weight and body-measurements would have materially changed in the intervening period.

The recent work of Oppenheimer[1] may be of value in suggesting some comparative basis for obtaining information regarding the different states of nutrition. Unfortunately all the measurements used by Oppenheimer were not taken upon our subjects and we cannot apply the method, but it is planned to take these measurements in some of the subsequent experiments.

The larger proportion of the subjects were young men, mostly college students; hence the values obtained in these experiments deal for the greater part with this class, and the investigation as a whole can only serve as a contribution to our knowledge of the metabolism of young, healthy, normal men. One or two of the individuals were very young, 16 or 17 years of age; there was one group of men between 30 and 40, and 2 individuals were from 55 to 60 years of age; 2 women were also used as subjects.

The following discussion of metabolism as influenced by differences in body-weight, height, and general physical characteristics is based on data by no means as elaborate as those of Sondén and Tigerstedt and of Magnus-Levy and Falk. On the other hand, certain factors that could not be determined by either of these investigators are here reported.

INFLUENCE OF WEIGHT, HEIGHT, AND AGE ON METABOLISM DURING SLEEP.

From among those subjects whose metabolism was studied during sleep we are able to select a few of different types. These are recorded in table 97. The classification includes, of course, many experiments with the same individuals that are grouped under other heads; thus, the two subjects W. O. A. and H. F. were both between 54 and 59 years of age and are also characterized as short, fat men.

Comparing the men according to the height and weight first, we find four classifications—short fat men, lean men, tall men, and short men (groups I, II, III, and IV), respectively. As has been pointed out in the preceding paragraph, it was very difficult to make the classification at the time of the compilation and a large element of personal impression must enter into the grouping.

The excretion of water-vapor is subject to so many variable factors that it is unnecessary to discuss it here. The heat produced per kilogram per hour is noticeably less with the two short fat men than with any other group, while the two lean men indicated the highest values. On the basis of per square meter of body-surface per hour, the two fat men also showed the lowest heat-production. A single exception to this is the case of A. H. M., a tall man, with but 29.1 calories. This subject has been used in a number of experiments and he invariably indicates a decidedly low metabolism. The average pulse-rate of this subject is also very much lower than normal. If the averages of the various groups

[1] Oppenheimer, Deutsche med. Woch., 1909, 35, p. 1835.

are taken, the lean men will clearly show the highest heat-production per square meter of body-surface. The excretion of carbon dioxide is noticeably lower with the two fat men than with any other group. This is also true with regard to the carbon-dioxide excretion per square meter of body-surface. The oxygen consumption is likewise very low for these men, both on the basis of per kilogram per minute, and also on the basis of per square meter of body-surface. The average high values for both the carbon dioxide and oxygen are again exhibited by the two lean men. From this short and admittedly imperfect classification, therefore, it would appear that the lean men exhibited a noticeably higher metabolism than any of the other groups, as is indicated not only by the carbon-dioxide excretion and oxygen consumption, but likewise by the heat production.

TABLE 97.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat produced by subjects according to physical characteristics and age, during sleep.*

Group and subject.	Body-weight (without clothing).	Height	Per kilogram per hour.		Per square meter of body-surface per hour.		Cubic centimeters per kilogram per minute.		Cubic centimeters per square meter of body-surface per minute.	
			Water vaporized.	Heat produced.	Water vaporized.	Heat produced.	Carbon dioxide eliminated.	Oxygen absorbed.	Carbon dioxide eliminated.	Oxygen absorbed.
Group I.										
Short fat men:	*Kilos.*	*cm.*	*Gram.*	*Cal.*	*Grams.*	*Cals.*				
W. O. A.	84.7	168	0.41	0.86	14.7	30.7	2.35	2.92	83.9	104
H. F.	71.2	168	.43	0.94	14.6	31.8	2.61	3.27	87.7	110
Group II.										
Lean men:										
H. E. S.	56.6	178	.52	1.37	16.2	42.7	3.41	4.66	106.5	145
H. R. D.	56.2	171	.44	1.16	13.8	36.2	3.18	3.99	99.0	124
Group III.										
Tall men:										
H. C. K.	72.0	181	.42	1.04	14.2	35.2	2.92	3.55	98.8	120
D. W.	78.3	180	.36	1.04	12.4	36.1	2.88	3.61	100.0	125
A. H. M.	61.6	179	.41	0.91	13.2	29.1	2.67	3.53	85.6	113
Group IV.										
Short men:										
O. F. T.	57.2	168	...	....	....	....	3.56	....	111.3	...
A. L. L.	71.5	166	.50	1.13	16.8	38.1	3.03	3.78	102.2	127
S. A. B.	57.0	166	.47	1.05	14.7	32.9	2.96	3.61	92.6	113
H. L. K.	55.0	166	.52	1.09	16.0	33.7	2.99	3.75	92.3	116
F. E. S.	56.1	163	...	1.16	....	36.2	....	....	....	...
Group V.										
Age, under 20 years:										
C. R. Y.	66.1	170	.68	1.12	22.2	36.6	3.22	3.87	105.7	127
H. A.	64.1	170	...	1.25	....	40.8	3.64	4.70	118.4	153
H. E. S.	56.6	178	.52	1.37	16.2	42.7	3.41	4.66	106.5	145
H. R. D.	56.2	171	.44	1.16	13.8	36.2	3.18	3.99	99.0	124
Group VI.										
Age, 54-59 years:										
W. O. A.	84.7	168	.41	0.86	14.7	30.7	2.35	2.92	83.9	104
H. F.	71.2	168	.43	0.94	14.6	31.8	2.61	3.27	87.7	110
Average during sleep[1]	....	....	.48	1.07	15.9	35.8	3.01	3.75	98.6	123

[1] These averages have been taken from the general tables for water, carbon dioxide, oxygen, and heat during sleep.

The classification by age is extremely unsatisfactory in that we have but 2 individuals in one of the groups. The two subjects with the low metabolism who were included in the group of short fat men are likewise classified in the group of subjects from 54 to 59 years of age, and we here deal with the question as to whether this low metabolism was due to age or to the physical characteristics of these men. These points the experiments will not answer and obviously we must await the accumulation of further data.

The average values given at the foot of table 97 are not the averages of the experiments here given, but the averages of all the experiments we have with subjects during sleep. They are taken from the general tables 55, 67, 71, and 75, and represent, we believe, the average for individuals of body-weight and physical condition reported upon here. It would seem that on the whole there is not as striking a difference between the groups of tall men and short men when compared with the average. On the other hand, the lean men have a distinctly higher metabolism and the short fat men, group I, a distinctly lower metabolism. Those subjects under 20 years have a noticeably higher metabolism than the older subjects, and their metabolism is considerably higher than the average.

INFLUENCE OF WEIGHT, HEIGHT, AND AGE ON METABOLISM DURING WAKING HOURS.

In connection with the researches at Wesleyan University, a large number of short experiments were made during the day on certain individuals with striking physical characteristics which permit of their being classified into groups similar to those in table 97. These experiments were much shorter and hence have not the accuracy of the longer experiments which included night periods. The results of these short experiments, grouped together with the values for the waking hours of the subjects in the sleeping experiments, are given in table 98. This grouping amplifies the list of subjects considerably, and we have a somewhat better basis for a discussion of the variations in the type of individuals. The average results at the foot of the table represent the results obtained on 55 different subjects during waking hours and not the average of the experiments in the table. The short fat men, group I, have, as a rule, a considerably lower metabolism than any of the other classes, while the lean men, group II, as a class have the highest metabolism. As in the preceding table, certain individuals are here grouped under more than one head as, for instance, H. L. W. and G. H. H. are classified under both lean men and short men, and W. R. L. and F. L. T. under both lean men and tall men. Considering the results on the basis of heat production, we find that group I is considerably lower than normal, group II is considerably higher, and groups III and IV have an average heat production not far from the normal. The carbon-dioxide production and oxygen consumption are very low with the short fat men, somewhat above the average with group II, and not far from the average with groups III and IV.

TABLE 98.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat produced by subjects according to physical characteristics and age, during waking hours in rest experiments.*

Group and subject.	Body-weight (without clothing).	Height	Per kilogram per hour.		Per square meter of body-surface per hour.		Cubic centimeters per kilogram per minute.		Cubic centimeters per square meter of body-surface per minute.	
			Water vaporized.	Heat produced.	Water vaporized.	Heat produced.	Carbon dioxide eliminated.	Oxygen absorbed.	Carbon dioxide eliminated.	Oxygen absorbed.
Group I.										
Short fat men:	*Kilos.*	*cm.*	*Gram.*	*Cals.*	*Grams.*	*Cals.*				
H. C. M.	86.3	166	0.55	1.27	19.7	45.4	3.76	4.14	135	148
W. O. A.	84.8	168	.43	1.31	15.3	46.6	3.82	4.53	136	162
S. C. D.	74.9	178	.59	1.32	20.2	45.2	4.00	4.42	137	152
H. F.	71.2	168	.42	1.21	14.0	40.7	3.57	4.00	120	135
Group II.										
Lean men:										
W. R. L.	74.9	198	.58	1.47	19.7	50.1	4.45	4.67	153	160
F. L. T.	64.3	192	.65	1.66	21.2	53.7	4.86	5.79	159	188
J. A. R.	59.2	180	.55	1.51	17.1	47.8	4.45	4.59	141	145
G. E. H.	63.2	179	.53	1.34	17.2	43.5	3.61	3.77	117	122
H. E. S.	57.2	178	.48	1.44	14.9	44.9	4.07	5.10	127	159
J. W. H.	60.9	175	.77	1.83	24.6	58.3	5.52	6.20	176	198
C. A. R.	59.0	174	.63	1.61	20.7	50.8	4.66	5.03	147	159
G. W. S.	51.5	173	.70	1.71	20.8	51.5	4.83	5.26	146	159
H. R. D.	57.5	171	.45	1.32	14.0	41.4	3.82	4.55	120	143
T. M. C.	50.5	166	.67	1.71	20.0	51.4	4.62	5.48	139	165
H. L. W.	51.8	164	.79	1.79	23.8	53.9	4.80	5.45	145	164
G. H. H.	51.7	163	.68	1.76	20.4	52.8	5.17	6.04	156	182
H. G.	49.2	160	.66	1.63	19.8	48.5	4.77	4.72	142	141
Group III.										
Tall men:										
W. R. L.	74.9	198	.58	1.47	19.7	50.1	4.45	4.67	153	160
F. L. T.	64.3	192	.65	1.66	21.2	53.7	4.86	5.79	159	188
F. G. B.	83.2	183	.50	1.20	17.6	42.5	3.89	4.47	138	158
F. C. B.	73.6	183	.63	1.51	21.5	51.1	4.21	5.26	143	172
J. R.	69.2	183	.57	1.51	19.0	50.1	4.59	5.00	153	166
H. C. K.	72.6	181	.49	1.25	16.6	42.5	3.47	4.34	117	147
D. W.	77.4	180	.47	1.30	16.3	44.9	3.73	4.70	129	163
A. H. M.	64.3	179	.45	1.30	14.7	42.2	3.56	4.29	116	139
Group IV.										
Short men:										
O. F. T.	57.2	168	....	....	....	....	5.70	....	178	...
A. L. L.	70.8	166	.49	1.30	16.6	43.7	3.62	4.52	122	152
S. A. B.	56.4	166	.47	1.44	14.7	44.7	3.94	5.02	123	156
H. L. K.	55.6	166	.63	1.65	19.5	51.1	4.77	5.52	148	171
H. L. W.	51.8	164	.79	1.79	23.8	53.9	4.80	5.45	145	164
G. H. H.	51.7	163	.68	1.76	20.4	52.8	5.17	6.04	156	182
H. G.	49.2	160	.66	1.63	19.8	48.5	4.77	4.72	142	141
Group V.										
Age under 20 years:										
C. R. Y.	66.4	170	.58	1.48	18.9	48.5	4.35	5.00	141	164
H. A.	64.1	170	.71	1.44	23.0	46.7	4.54	6.07	148	197
C. F. B.	62.2	170	.63	1.77	20.4	57.0	4.92	5.79	158	186
C. A. R.	59.0	174	.66	1.61	20.7	50.8	4.66	5.03	147	159
F. N. C.	57.6	168	.60	1.73	18.9	54.2	4.99	5.48	157	172
H. R. D.	57.5	171	.45	1.32	14.0	41.4	3.82	4.55	120	143
H. E. S.	57.2	178	.48	1.44	14.9	44.9	4.07	5.10	127	159
B. N.	46.4	168	1.00	1.86	29.2	54.2	5.60	6.18	164	181
Group VI.										
Age, 34 to 36 years:										
F. G. B.	83.2	183	.50	1.20	17.6	42.5	3.89	4.47	138	158
R. D. M.	70.4	178	.58	1.32	19.3	43.9	3.92	4.30	132	144
N. B.	66.0	172	.60	1.40	19.8	45.9	3.73	4.03	123	132
F. W. H.	58.4	173	.74	1.55	23.3	48.7	4.51	5.07	142	160
Group VII.										
Age, 54 to 59 years:										
W. O. A.	84.8	168	.43	1.31	15.3	46.6	3.82	4.53	136	162
H. F.	71.2	168	.42	1.21	14.0	40.7	3.57	4.00	120	135
Average during waking hrs.[1]	....	....	.61	1.52	19.7	49.2	4.42	4.96	143	160

[1] These averages have been taken from the general tables for water, carbon dioxide, oxygen, and heat during waking hours.

On the basis of age, group V (those under 20 years of age) exhibited a total metabolism somewhat above the normal, as indicated by the heat production as well as by the carbon-dioxide production and oxygen consumption, while groups VI (those between 34 and 36 years of age) and VII (those between 54 and 59 years of age) are noticeably below the normal.

From the results presented in table 98, therefore, it is seen that the lean men have the highest metabolism and the short fat men, the lowest; while on the basis of age, the young men have the highest metabolism, the older people, the lowest, and the intermediate age an intermediate metabolism. So far as physical characteristics are concerned, this is wholly in agreement with the idea that the total metabolism is determined in large part by the proportion of active protoplasmic tissue in the body. This would naturally be somewhat larger with lean men than with short fat men, and hence the higher metabolism would be expected with the former group. The tendency for elderly people to accumulate fatty tissue may likewise account for the variations in metabolism with age. The possibility of protoplasmic tissue having a decreased metabolic activity in old age as pointed out by Magnus-Levy and Falk[1] should also be considered. Those in group VII were men who were distinctly fat. In group VI, 2 individuals were fat; one was an athlete, and the other of normal build. The young men in group V were all free from visible evidence of a large amount of superfluous fat. The results, therefore, plainly do not indicate whether or not age, *per se,* has an influence on metabolism.

COMPARISON OF THE METABOLISM OF ATHLETES AND NON-ATHLETES.

If the assumption is true that the proportion of active protoplasmic tissue present in the body plays an important rôle in determining the total metabolism, we would expect *à priori* that trained athletes with a large amount of muscular tissue would show a larger metabolism when at rest than other individuals with similar body-weight and size. Among the subjects experimented with in the respiration chamber were a number of athletes. In table 99 the results are given with these athletes and for purposes of comparison the results with a number of individuals of approximately the same body-weight are also given.

With the subject D. W. the metabolism, as indicated by the carbon-dioxide production, and heat production, is on the whole considerably lower than that with the group of non-athletes with which he is compared. With the subject J. C. W. only carbon dioxide and heat were determined, but here again the metabolism is lower than with the four non-athletes with whom he is compared. In the case of the professional athlete N. B., we have a similar condition, namely, a markedly lower excretion of carbon dioxide and absorption of oxygen and a somewhat lower heat production than the average of the group of individuals with whom he is compared. We have but 2 experiments, 3 hours each, with the athlete H. G., but, as was found with the other 3 athletes, the total metabolism per kilogram of body-weight and per square meter of body-surface seems to be distinctly lower than with subjects of similar body-weight.

[1] Magnus-Levy and Falk., *loc. cit.*, p. 342.

TABLE 99.—*Carbon dioxide eliminated, oxygen absorbed, and heat produced by athletes and non-athletic men during waking hours in rest experiments.*

Subject and group.	Body-weight (without clothing).	Height.	Cubic centimeters per kilogram per minute.		Cubic centimeters per square meter of body-surface per minute.		Heat produced.	
			Carbon dioxide eliminated.	Oxygen absorbed.	Carbon dioxide eliminated.	Oxygen absorbed.	Per kilogram per hour.	Per square meter of body-surface per hour.
	Kilos.	*cm.*					*Cals.*	*Cals.*
D. W. (athlete).....	77.4	180	3.73	4.70	129	163	1.30	44.9
Non-athletes:								
G. G. R..........	77.2	178	4.10	4.12	143	145	1.42	49.5
W. R. L..........	74.9	198	4.45	4.67	153	160	1.47	50.1
S. C. D..........	74.9	178	4.00	4.42	137	152	1.32	45.2
F. C. B..........	73.6	183	4.21	6.26	143	172	1.51	51.1
H. C. K..........	72.6	181	3.47	4.34	117	147	1.25	42.5
R. D. M..........	70.4	178	3.92	4.30	132	144	1.32	43.9
A. W. S..........	69.7	176	4.70	....	157	....	1.60	53.2
N. M. P..........	69.1	177	4.38	5.01	146	167	1.56	52.0
Average of non-athletes	....	....	4.15	4.59	141	155	1.43	48.4
J. C. W. (athlete)..	75.8	178	3.76	....	129	....	1.36	46.9
Non-athletes:								
G. G. R..........	77.2	178	4.10	4.12	143	145	1.42	49.5
S. C. D..........	74.9	178	4.00	4.42	137	152	1.32	45.2
F. C. B..........	73.6	183	4.21	5.26	143	172	1.51	51.1
H. C. K..........	72.6	181	3.47	4.34	117	147	1.25	42.5
Average of non-athletes	....	....	3.95	4.54	135	154	1.38	47.1
N. B. (athlete)......	66.0	172	3.73	4.03	123	132	1.40	45.9
Non-athletes:								
A. W. S..........	69.7	176	4.70	....	157	....	1.60	53.2
A. M.	66.9	175	4.64	4.80	153	158	1.60	52.7
H. A. P..........	64.3	180	3.98	4.38	130	142	1.32	43.1
A. H. M..........	64.3	179	3.56	4.29	116	139	1.30	42.2
E. M. S..........	64.3	175	4.29	4.49	140	146	1.61	52.3
G. E. H..........	63.2	179	3.61	3.77	117	122	1.34	43.5
J. V. C..........	63.2	173	4.47	5.01	145	162	1.65	53.5
D. R. F..........	62.4	173	4.53	4.57	146	147	1.43	46.1
A. G.	62.3	170	4.78	5.29	154	171	1.61	51.8
F. N. C..........	57.6	168	4.99	5.48	157	172	1.73	54.2
H. R. D..........	57.5	171	3.82	4.55	120	143	1.32	41.4
Average of non-athletes	....	....	4.31	4.66	140	150	1.50	48.5
H. G. (athlete).....	49.2	160	4.77	4.72	142	141	1.63	48.5
Non-athletes:								
H. L. K..........	55.6	166	4.77	5.52	148	171	1.65	51.1
F. E. R..........	52.2	168	4.74	5.05	144	154	1.80	54.8
H. L. W..........	51.8	164	4.80	5.45	145	164	1.79	53.9
G. H. H..........	51.7	163	5.17	6.04	156	182	1.76	52.8
G. W. S..........	51.5	173	4.83	5.26	146	159	1.71	51.5
T. M. C..........	50.5	166	4.62	5.48	139	165	1.71	51.4
Average of non-athletes	....	....	4.82	5.47	146	166	1.74	52.6
Average during waking hrs.[1].	....	....	4.42	4.96	143	160	1.52	49.2

[1] These averages have been taken from the general tables for carbon dioxide, oxygen, and heat during waking hours.

These results are entirely at variance with what would naturally be expected from most of the early researches. The fact that the results are so uniformly low with 4 different subjects can not be overlooked and yet we wish to state distinctly that the experiments were not planned primarily with the idea of studying athletes and comparing them with a group of non-athletes and hence, before final conclusions are made, we hope to have a series of experiments in which this special problem is studied by itself. A careful comparison of all records made during the experiments offers no plausible explanation for the decreased metabolism. Furthermore, the possibility of a compensation in that during rest the metabolism is low to counterbalance the high metabolism during work, can hardly be accepted, for, in the first place, with 2 of the subjects, D. W. and J. C. W., the experiments continued for two or more days, during which time the subjects were not engaged in any muscular work, and in the second place, the evidence as shown by the results of experiments following work points strongly to an increased rather than decreased katabolism in sleep following work.

COMPARISON OF THE METABOLISM OF WOMEN AND NON-ATHLETES.

With 2 women subjects a number of experiments were made giving satisfactory duplicates for each individual. The subject remained quietly sitting in the chamber without any extraneous effort, and to all appearances the experiments are perfectly comparable with a large number of experiments made with men. In table 100 the experiments with each woman are compared with a number of men of non-athletic build who were approximately of the same body-weight, but in all cases considerably taller. The total metabolism as indicated by the heat production, oxygen consumption, and carbon-dioxide excretion is noticeably lower with these women than with nearly all of the men. This is particularly the case with the heat production. For purposes of comparison, the average of all experiments on resting men are given in the last line of the table. The heat production per kilogram per hour with C. F. S. was 1.15 calories, and with G. E. B., 1.00 calories. The lowest value obtained on any of the men with whom they are compared was 1.30 calories. In the case of C. F. S. there are two men who exhaled somewhat lower amounts of carbon dioxide per minute and one who absorbed somewhat less oxygen. With G. E. B., none of the men approximated the low excretion of carbon dioxide or the low oxygen consumption. In general, then, the total metabolism of these 2 women was noticeably lower than with men of similar body-weight.

Setting aside all differences in physical characteristics and in sex of two people of the same body-weight and general conformation, the taller person will have the less subcutaneous fat, and women as a class have a larger amount of subcutaneous fat than men. Consequently, the active mass of protoplasmic tissue would be somewhat less with women than with men, and if this is the controlling factor of metabolism, we would expect a lower metabolism. We also

would expect that the values obtained on women would compare more exactly per kilogram of body-weight with those obtained on fat men and an examination of table 98 shows us that the group of fat men do exhibit a low heat production on the average, although both the carbon-dioxide excretion and oxygen consumption are somewhat greater than with the women.

These results are more in accord with the results of Sondén and Tigerstedt[1] which showed a marked difference between men and women, and are at variance with the results of Magnus-Levy and Falk,[2] who do not find the differences appreciable. Furthermore, the criticism raised with regard to the experiments of Sondén and Tigerstedt that the women were more quiet as a rule than the men with whom they were compared hardly applies here, for in all instances the persons remained quietly seated in the chair inside the chamber. It is obviously

TABLE 100.—*Water vaporized, carbon dioxide eliminated, oxygen absorbed, and heat produced by women and non-athletic men during waking hours in rest experiments.*

Group and subject.	Body-weight (without clothing).	Height	Per kilogram per hour.		Per square meter of body-surface per hour.		Cubic centimeters per kilogram per minute.		Cubic centimeters per square meter of body-surface per minute.	
			Water vaporized.	Heat produced.	Water vaporized.	Heat produced.	Carbon dioxide eliminated.	Oxygen absorbed.	Carbon dioxide eliminated.	Oxygen absorbed.
	Kilos.	*cm.*	*Gram.*	*Cals.*	*Grams.*	*Cals.*				
C. F. S. (woman)..	62.6	161	0.77	1.15	24.7	37.1	3.64	3.86	117	124
Non-athletic men:										
H. A. P..........	64.8	180	.72	1.32	23.6	43.1	3.98	4.38	130	142
A. H. M..........	64.3	179	.45	1.30	14.7	42.2	3.56	4.29	116	139
E. M. S..........	64.3	175	.62	1.61	20.2	52.3	4.29	4.49	140	146
G. E. H..........	63.2	179	.53	1.34	17.2	43.5	3.61	3.77	117	122
J. V. C..........	63.2	173	.69	1.65	22.4	53.5	4.47	5.01	145	162
D. R. F..........	62.4	178	.53	1.43	16.8	46.1	4.53	4.57	146	147
Average of non-athletic men.	....	....	.59	1.44	19.2	46.8	4.07	4.42	132	143
G. E. B. (woman)..	57.2	157	.77	1.00	24.1	31.2	3.26	3.91	102	123
Non-athletic men:										
F. W. H..........	58.4	173	.74	1.55	23.3	48.7	4.51	5.07	142	160
F. N. C..........	57.6	168	.60	1.73	18.9	54.2	4.99	5.48	157	172
H. R. D..........	57.5	171	.45	1.32	14.0	41.4	3.82	4.55	120	143
H. E. S..........	57.2	178	.48	1.44	14.9	44.9	4.07	5.10	127	159
H. L. K..........	55.6	166	.63	1.65	19.5	51.1	4.77	5.52	148	171
Average of non-athletic men.	....	....	.58	1.54	18.1	48.1	4.43	5.14	139	161
Average of men during waking hours[1]..	....	....	.61	1.53	19.7	49.2	4.42	4.96	143	160

[1] These averages have been taken from the general tables for water, carbon dioxide, oxygen, and heat during waking hours.

[1] Sondén and Tigerstedt, *loc. cit.*, p. 95.

[2] Magnus-Levy and Falk, *loc. cit.*, p. 344.

erroneous to draw deductions from experiments on only 2 individuals, but we are inclined to think that the difference in chemical composition of the body as a whole, and the larger proportion of fatty tissue would account for the lower metabolism that women exhibit as compared with men.

In previous discussions in this section but little attention has been given to the water of vaporization. In this one regard there seems to be an especially noticeable difference between the metabolism of women and men. A comparison of the values given in table 100 for the 2 women with the results on 55 men at rest shows that the 2 women excreted per kilogram of body-weight per hour considerably more water-vapor than did all but 4 of the 55 men. A recent (November, 1909) experiment with a woman in the Nutrition Laboratory showed, also, a very much larger water vaporization per hour than with men subjects, thus further confirming the observations reported on the subjects C. F. S. and G. E. B.

The previous experimental evidence with regard to the water-vapor excretion of women as compared with men is unfortunately very limited. In the experiments of Sondén and Tigerstedt the determinations of water-vapor were not made in all experiments with men and with women, but the authors point out that the relation of carbon dioxide to water-vapor with men is not far from 100:106, while with women the relation is as 100:134. Clearly, then, this relation of itself does not indicate anything definite with regard to the point under discussion, namely, the absolute output of women as compared with men, for the relationship may be larger with women than with men in that the carbon-dioxide excretion was smaller rather than the water vaporization larger.

In this connection it is somewhat interesting to consider the results obtained with a fat man by Schattenfroh[1] in Rubner's laboratory. As a result of his experiments, Schattenfroh concluded that fat people exhale considerably more water-vapor per square meter of body-surface than do lean people. If this is the case, then, we have a natural explanation of the apparently higher water vaporization of women than of men, inasmuch as there is admittedly a much larger proportion of subcutaneous fat per kilogram of body-weight with women than with men, and consequently the body of a woman would approximate in chemical composition that of a fat man.

It is obvious that the results are sufficiently characteristic to justify further experiments. The actual determined differences in the metabolism of men and women are too few and hence this apparently sharply defined point should be thoroughly substantiated by a large number of experiments.

[1] Schattenfroh, Archiv f. Hygiene, 1900, 38, p. 93.

VARIATIONS IN METABOLISM DUE TO VARIATIONS IN MUSCULAR ACTIVITY.

COMPARISON OF THE METABOLISM WHILE LYING AWAKE WITH METABOLISM DURING SLEEP.

The complete relaxation of the musculature during sleep results in a very low metabolism. When lying awake, certain individuals have been able by training to simulate this relaxation of the muscles to such an extent that the carbon-dioxide production, the only factor measured, has been lowered to practically that during sleep. The experiments of Johansson[1] in Stockholm have been cited frequently to illustrate the fact that with complete muscular relaxation, the carbon-dioxide production may be the same as that of sleep. Experiments are made with the Zuntz-Geppert apparatus when the subjects are lying awake with complete muscular relaxation, but this apparatus does not permit satisfactory experiments when the subjects are asleep. In certain of the experiments here reported, plans were made to study the metabolism when lying awake in the forenoon covered with a blanket on a cot and to compare the metabolism during this period with that of the period from 1 a. m. to 7 a. m. when the subjects were in the same body-position but in all probability asleep. These experiments, however, are not easily compared. It is very difficult to secure satisfactory experiments of this kind, but 6 have been collected as indicating in a general way the variations in metabolism. Of these 6, 3, we believe, should not be considered as strictly comparable, since the lying-awake period did not immediately follow the sleeping period and other factors affecting metabolism may have had an influence. They are reported in table 101, but are left out of the average. The other 3 (2 with the subject H. C. K. and 1 with the subject H. R. D.) are strictly comparable. The subjects slept during the night and the next morning remained in bed instead of rising. The metabolism during the morning period was, therefore, measured under practically the same conditions as during the night, except that the subjects were awake. In this way we obtained the best possible comparison of the metabolism under the two conditions.

With the three subjects A. H. M., C. R. Y. and J. H. K. we find that there is an increase in the metabolism during the lying-awake period as compared with the period when the subject lay asleep amounting to over 25 per cent on the average for the carbon-dioxide excretion, nearly 30 per cent for the oxygen absorption, and about 25 per cent for the heat production. The water vaporization shows very wide fluctuations, but as has been frequently pointed out in a previous discussion, it is without significance. With the three more strictly comparable experiments we find an increase on the average of 10 per cent in the carbon-dioxide excretion, practically no change in the water vaporization, 4.7 per cent in the oxygen absorption, and 11.4 per cent in the heat production.

From these experiments, therefore, it can be stated that there is a material increase in the metabolism when the subject is lying awake over that when lying

[1] Johansson, Skand. Archiv f. Physiol., 1898, 8, p. 85.

asleep. As a matter of fact, from frequent observations of the pulse-rate when the subject is lying awake and when lying asleep, we find an increased heart-beat and a somewhat higher respiration-rate. It is to be expected, therefore, that the metabolism would be higher. Unfortunately, in the experiments of Johansson[1] no information whatever is given in regard to the pulse-rate, and we have no

TABLE 101.—*Metabolism in experiments while lying awake compared with metabolism while lying asleep.*

[Amounts per hour.]

Subject.	Metabolism.	(a) Lying asleep.	(b) Lying awake.	(c) Increase. (b−a)	(d) Percentage increase. (c÷a)
		Grams.	*Grams.*	*Grams.*	*P. ct.*
A. H. M.[1]	Water vaporized	28.3	29.9	1.6	5.7
C. R. Y.[1]	Do.	49.5	42.9	−6.6	−13.3
J. H. K.[1]	Do.	28.1	37.0	8.9	31.7
H. C. K.	Do.	31.2	30.2	−1.0	− 3.2
H. C. K.	Do.	30.7	30.5	−0.2	− 0.7
H. R. D.	Do.	23.5	24.3	0.8	3.4
Average		....	....	− 0.1	− 0.2
A. H. M.[1]	Carbon dioxide eliminated	18.8	27.4	8.6	45.7
C. R. Y.[1]	Do.	25.7	31.2	5.5	21.4
J. H. K.[1]	Do.	21.4	24.6	3.2	15.0
H. C. K.	Do.	25.4	27.5	2.1	8.3
H. C. K.	Do.	24.2	26.5	2.3	9.5
H. R. D.	Do.	21.6	24.4	2.8	13.0
Average		....	....	2.4	10.3
A. H. M.[1]	Oxygen absorbed	15.2	21.4	6.2	40.8
C. R. Y.[1]	Do.	22.3	26.3	4.0	17.9
J. H. K.[1]	Do.	18.3	21.9	3.6	19.7
H. C. K.	Do.	23.6	24.0	0.4	1.7
H. C. K.	Do.	22.4	22.6	0.2	0.9
H. R. D.	Do.	19.2	21.4	2.2	11.5
Average		....	....	0.9	4.7
		Cals.	*Cals.*	*Cals.*	
A. H. M.[1]	Heat produced	53.5	70.5	17.0	31.8
C. R. Y.[1]	Do.	77.7	105.9	28.2	36.3
J. H. K.[1]	Do.	61.8	75.9	14.1	22.8
H. C. K.	Do.	79.2	83.8	4.6	5.8
H. C. K.	Do.	73.1	84.2	11.1	15.2
H. R. D.	Do.	63.2	71.5	8.3	13.1
Average		....	....	8.0	11.4

[1] A. H. M., C. R. Y., and J. H. K. were not included in the averages.

means of comparing it. It would seem, however, that with increased pulse and respiration rates, there would be an accompanying increase in muscular tonus which would of necessity result in an increased metabolism. In general, then, we may state that the metabolism when lying awake is from 8 to 10 per cent greater than with the same subject lying asleep. This is obviously of special importance in considering the calorific requirement of bedridden patients.

[1] Johansson, *loc. cit.*

COMPARISON OF METABOLISM WHILE SITTING WITH METABOLISM WHILE STANDING.

When the subject is quietly seated in a chair, the metabolism is invariably somewhat higher than when he is lying on a bed asleep. If a subject is trained to so regulate the muscular tension by his will as to reduce it to the minimum, the differences in the carbon-dioxide excretion during such muscular relaxation when lying down awake and when asleep are not measurable. On the other hand, sitting up calls for a different readjustment of the muscular system with variations in the tonus and the sitting posture does not permit of as complete a relaxation of muscular tension as does lying down. Standing requires a still further readjustment of muscular tension and the variations in metabolism between sitting and standing are of unusual interest. Many individuals stand the greater part of the day while at work, at a bookkeeper's desk, for instance, or at other occupations which do not demand strenuous muscular exercise, but do require a standing position. In order to throw some light upon the variations in metabolism when standing as compared with sitting, 5 experiments were made in which the subjects sat for 2 to 4 hours and immediately afterwards stood for 2 to 3 hours. During the two periods the four factors of the grosser metabolism were measured. The results have been gathered in table 102.

As might have been expected, there is an increase in practically all the experiments during the standing period, although singularly enough with the subject H. R. D., there was a lowered carbon-dioxide exhalation, and water vaporization, and a decreased oxygen absorption. On the other hand, there was a noticeable increase in the heat production. Likewise, in the first experiment with A. H. M. there was a slight decrease in the heat production when standing. These discrepancies serve to show admirably the difficulties attending experimentation in short periods, and the individual experiments and the individual periods must be looked upon as giving only tentative results. On the other hand, the average of 5 experiments can be considered a reasonably accurate index of the normal condition. As an average of the 5 experiments we find that there is an increase of carbon-dioxide elimination amounting to 3.1 grams, of water vaporized 2.2 grams, of oxygen absorbed 3.4 grams, and of heat produced 12.9 calories per hour. These values correspond to an increase in the carbon dioxide of 12.4 per cent, of water 6.9 per cent, of oxygen 15.2 per cent, and of heat 16.5 per cent. There is, then, on the average, an increase of about 15 per cent in the metabolism when a person stands over the metabolism when sitting.

This comparison brings into discussion the interesting relations between external muscular work and static work, a problem that has received much attention from Johansson[1] and his co-workers. The play of muscles required to hold the body in an upright position may be considered as very small and obviously the nicety with which the body is balanced, the less the work required

[1] Johansson, Skand. Archiv f. Physiol. 1901, 11, p. 273.

for the muscles to hold it in this position. In these experiments the subjects were by no means as careful to remain in an absolutely rigid fixed position as could be desired. On the other hand, they did not move about materially and the results may be taken as indicative of the metabolism when standing under ordinary conditions. There was, of course, a frequent shifting of weight from one foot to the other and now and then a slight movement of the feet, but on the whole the subjects remained quietly standing.

Working with the respiration chamber in Stockholm, Widlund[1] found that there was no increase in the carbon dioxide (the only factor measured) when standing in an easy position. If the muscles were tense he found that there was an increase. Obviously experiments of this kind involve the training of the subject to adjust himself in the best position for making the comparison and certainly the positions held by Widlund would not be normally considered as standing. It is conceivable that the balance may be so carefully adjusted and possibly the shoulders slightly braced so as to simply involve the work of supporting the weight of the body on the lower muscles of the legs and the muscles of the trunk. This would involve not much more work than simple balancing.

TABLE 102.—*Metabolism in experiments while sitting compared with metabolism while standing.*

[Amounts per hour.]

Subject.	Metabolism.	(*a*) Sitting.	(*b*) Standing.	(*c*) Increase. (*b*−*a*)	(*d*) Percentage increase. (*c*÷*a*)
		Grams.	*Grams.*	*Grams.*	*P. ct.*
A. H. M.	Water vaporized	27.5	29.6	2.1	7.6
A. H. M.	Do.	25.6	28.2	2.6	10.2
A. L. L.	Do.	27.8	29.3	1.5	5.4
H. R. D.	Do.	25.4	25.2	− 0.2	− 0.8
B. F. D.	Do.	40.4	45.3	4.9	12.1
Average		....	....	2.2	6.9
A. H. M.	Carbon dioxide eliminated	25.5	29.5	4.0	15.7
A. H. M.	Do.	23.1	28.5	5.4	23.4
A. L. L.	Do.	24.5	26.1	1.6	6.5
H. R. D.	Do.	27.5	25.2	− 2.3	− 8.4
B. F. D.	Do.	27.2	33.9	6.7	24.6
Average		....	....	3.1	12.4
A. H. M.	Oxygen absorbed	19.3	23.7	4.4	22.8
A. H. M.	Do.	21.5	26.2	4.7	21.9
A. L. L.	Do.	21.7	25.6	3.9	18.0
H. R. D.	Do.	21.0	18.9	− 2.1	−10.0
B. F. D.	Do.	25.5	31.4	5.9	23.1
Average		....	....	3.4	15.2
		Cals.	*Cals.*	*Cals.*	*P. ct.*
A. H. M.	Heat produced	73.7	73.3	− 0.4	− 0.5
A. H. M.	Do.	72.3	81.9	9.6	13.3
A. L. L.	Do.	73.7	98.6	24.9	33.8
H. R. D.	Do.	73.0	86.4	13.4	18.4
B. F. D.	Do.	97.2	114.4	17.2	17.7
Average		....	....	12.9	16.5

[1] Widlund, Skand. Archiv f. Physiol., 1905, 17, p. 290.

For practical purposes, and that is the chief object of the investigation here reported, we may consider that the metabolism when standing is about 15 per cent greater than that when sitting.

INCREASE IN METABOLISM DUE TO OPENING AND CLOSING FOOD APERTURE.

To remove food and dishes from the food aperture and to place therein the vessels containing urine and feces requires a simple series of movements on the part of the subject that must be made several times during the day. Inasmuch as this is the most complicated series of muscular movements involved in a sojourn inside the respiration chamber aside from the work of taking down and putting up the bed, a series of experiments was made to study the increased heat output that results from the operation of opening the food aperture. In this operation as usually carried out the subject rises from an arm-chair, takes one or at the most two steps to the food aperture, unscrews with the right hand the clamp which holds the door, opens it, takes out the material, closes the door, screws down the clamp, and returns to the arm-chair. The experiments in which the increased metabolism was studied were so planned as to have this series of movements carried out with great regularity 12 times each hour and there was activity beyond that just outlined in that the subject opened and closed the food aperture twice during the series of movements. During a preliminary period of 1 to 2 hours before each experiment the subject sat quietly in the chair till the apparatus was brought into equilibrium and then began the series of movements. After the beginning of the first period he arose every 5 minutes and went through the operation of opening and closing the food aperture, and carried out the series of movements with great regularity throughout the experiment. The time required by the different subjects for this operation varied somewhat, A. H. M. requiring 19 seconds, A. L. L. 29 seconds, and H. R. D. 26 seconds. The subjects were in each case without food since the preceding day. For comparison with these experiments, other experiments of different date with the same subjects have been used. In the latter experiments no food was eaten since the preceding day and the subjects sat quietly during the entire period of 8 hours. The results for the metabolism during rest and during the food aperture experiments are given in table 103.

There is a distinct increase in the metabolism during the active period as indicated by the carbon-dioxide exhalation, oxygen absorption, and heat production. The water vaporized varied somewhat, as has been pointed out previously. In the last column of the table all the increases are divided by 12, thus giving the amount of carbon dioxide exhaled, the oxygen absorbed, and the heat production in one series of movements. It can be seen that on the average for every time that the food aperture was opened there was an increase in the carbon-dioxide production of 0.42 gram, of oxygen absorption 0.57 gram, and of heat production 1.22 calories.

These subjects showed that when sitting at rest, fasting, they gave off 23.3 grams per hour of carbon dioxide, or about 0.4 gram of carbon dioxide per

minute. The oxygen absorbed amounted to 0.3 gram per minute, and the heat production to 1.2 calories per minute. It is thus seen that for each act of opening and closing the food aperture, which, on an average, occupied 25 seconds, the excretion of carbon dioxide and the heat production were approximately the same as in one minute of sitting (resting), or an increase of over 100 per cent. If the actual time required to carry out the operation is taken into consideration, the excess in heat production over that which would be produced during the time required for the operation would be 200 to 300 per cent.

When it is seen that rising from a chair, taking one step, and returning may involve an increased heat production over the resting metabolism of 100 per cent or more, it is clear that the sum total of minor body movements in the course of a day may actually accumulate to a considerable amount and thus raise the heat production during resting metabolism much more than one would ordinarily appreciate. This makes it extremely difficult to estimate beforehand the energy output of individuals where the minor muscular movements are not satisfactorily recorded. The experiments here reported are the result of an attempt to accumulate data regarding some of the simpler operations or movements which may take place in ordinary life. They have a practical value in connection with the interpretation of certain of the experiments made with this apparatus, but they likewise throw considerable light upon the metabolism involved in a simple body-movement.

TABLE 103.—*Increase in the metabolism in food-aperture experiments as compared with metabolism during rest.*

[Amounts per hour.]

Subject.	Metabolism.	(*a*) Sitting, in rest experiment without food.	(*b*) Food-aperture experiment without food.	(*c*) Increase. (*b*—*a*)	(*d*) Increase for each series of movements.[1] (*c*+12)
		Grams.	*Grams.*	*Grams.*	*Grams.*
A. H. M.	Water vaporized	23.9	31.4	7.5	0.63
A. L. L.	Do.	31.8	31.6	—0.2	—0.02
H. R. D.	Do.	22.8	25.7	2.9	0.24
Average		26.2	29.6	3.4	0.28
A. H. M.	Carbon dioxide eliminated	23.0	29.4	6.4	0.53
A. L. L.	Do.	23.4	28.9	5.5	0.46
H. R. D.	Do.	23.5	26.9	3.4	0.28
Average		23.3	28.4	5.1	0.42
A. H. M.	Oxygen absorbed	19.6	27.9	8.3	0.69
A. L. L.	Do.	20.3	24.9	4.6	0.38
H. R. D.	Do.	20.4	28.2	7.8	0.65
Average		20.1	27.0	6.9	0.57
		Cals.	*Cals.*	*Cals.*	*Cals.*
A. H. M.	Heat produced	72.2	92.9	20.7	1.73
A. L. L.	Do.	74.4	87.7	13.3	1.11
H. R. D.	Do.	71.5	81.4	9.9	0.83
Average		72.7	87.3	14.6	1.22

[1] For explanation of this series of movements see pp. 61 and 62.

INCREASE IN METABOLISM DUE TO DRESSING AND UNDRESSING.

At least twice each day most individuals remove or put on clothes. This operation involves some muscular work and likewise a portion or the whole of the body is for a longer or shorter period of time exposed to the air without surrounding clothing. With a view to obtaining some information with regard to the energy transformation taking place during such a process, 21 different men were used as subjects during experimental periods of 1 hour each in which the subjects were weighed, took off their clothes, were weighed again, remained naked an average of 3.5 minutes, then dressed themselves again, and immediately sat down. The results are given in table 104. Inasmuch as the period had been preceded by a resting period, the increase in metabolism was measured with reasonable accuracy. One great disadvantage with experiments of this kind, however, is that the measurement of the factors was confined to a 1-hour period, and as has been pointed out previously, even 2-hour periods do not give as accurate results as do longer experiments. However, it is assumed that an average of the total number of experiments will give a reasonably accurate picture of the increase in metabolism, although there are wide variations noted with individuals. During undressing and dressing, there was an average increase of 10.4 grams in the carbon-dioxide production over the resting, sitting value; 8.7 grams more oxygen were absorbed; and 17.8 calories more heat produced.

TABLE 104.—*Increase in the metabolism in experiments when the subjects undressed, weighed, and dressed as compared with metabolism during rest.*[1]

[Increase per hour.]

Subject.	Increase in carbon dioxide eliminated.	Increase in oxygen absorbed.	Increase in heat produced.	Subject.	Increase in carbon dioxide eliminated.	Increase in oxygen absorbed.	Increase in heat produced.
	Gms.	*Gms.*	*Cals.*		*Gms.*	*Gms.*	*Cals.*
H. G.	8.5	5.4	5.3	J. V. C.	6.6	5.1	1.5
H. L. W.	8.6	7.8	25.5	E. M. S.	13.9	11.0	5.6
F. E. R.	19.6	20.6	19.4	G. E. H.	12.7	31.8	7.3
F. N. C.	11.1	....	27.4	G. H. H.	10.2	4.2	18.4
H. C. A.	6.4	2.6	12.1	J. W. H.	8.4	7.4	16.6
N. M. P.	10.6	8.0	2.9	G. W. S.	9.1	8.4	16.7
J. A. R.	8.7	7.7	15.0				
H. D. A.	7.9	—3.7	21.4	Average	10.4	8.7	17.8
H. L. K.	15.2	3.2	23.2				
A. M.	18.1	20.9	39.5				
D. R. F.	—3.5	3.3	24.4				
J. N. T.	13.7	5.1	34.0	Average amount per hour during rest	32.6	25.6	98.2
C. A. R.	9.7	6.6	19.2				
A. G.	12.1	9.7	25.2				
G. G. R.	10.5	....	12.3	Percentage increase over rest	31.9	34.0	18.1

[1] The rest experiment in each case in this comparison was a period of 3 hours immediately preceding the period of dressing and undressing.

Here, again, it is distinctly impracticable to compare intelligently the increments in the various factors—carbon-dioxide elimination, oxygen consumption, and heat production. The increased respiration-rate may naturally result

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in a larger increase in the carbon-dioxide exhalation on account of a transitory withdrawal of carbon dioxide from the lungs; the heat production may also be affected by variations in body-temperature which could not be satisfactorily measured by the method here used, namely, a clinical thermometer in the mouth; and the oxygen absorption as measured in 1-hour periods is likewise open to serious error. On the other hand, the almost uniform increase in all factors in the experiments shows that there was a distinct increase in metabolism. We believe, then, that in the metabolism of 1 hour during the process of dressing and undressing there is an increase in the excretion of carbon dioxide amounting to about one-third of the excretion during rest, an increase of the oxygen absorption of about one-third, and an increase in the heat production of about one-fifth.

Evidence such as this, when sufficiently accumulated, will permit a much more accurate computation of the total energy transformations of man in 24 hours. Up to this time we have had no evidence whatever with regard to the energy transformations incidental to removing and putting on clothes. There is no reason why similar experiments should not be made for a large number of other simple body movements which are a part of every one's daily routine. Such experiments will be made as time permits and opportunity offers.

PULSE-RATE AS INDEX OF BODY ACTIVITY AND METABOLISM.

In any attempt to show quantitatively the variations in metabolism according to different degrees of muscular activity, difficulties are encountered. Designating the different degrees of activity as consisting of light, moderate, severe, and very severe muscular work does not convey an adequate impression of the muscular activity that actually may be involved in an experiment. In the pulse-rate we have a more accurate method of estimating the activity of normal individuals, and the metabolism that should accompany it. In the course of experiments it has been observed that with very slight activity the pulse and the metabolism are at a minimum. When the activity is increased, the pulse rate is likewise accelerated and there is an increase in the total metabolism. It has furthermore seemed clear that the increase in the pulse-rate is relatively proportional to the increase in the actual muscular activity observed. Of general interest in this connection is the practical application of these general principles by von Lützow [1] who estimates the capacity of horses for work by noting the lapse of time required for the pulse-rate to become normal after a period of work.

In an earlier investigation on the influence of inanition on metabolism, it was pointed out that the pulse-rate as determined by the subject from day to day during a 7-day fast varied with the total metabolism.[2] It was there shown that the pulse-rates as thus determined had not the highest scientific value,

[1] K. L. von Lützow, Deut. Landw. Presse, 1909, 36, p. 245.
[2] Benedict, Carnegie Institution of Washington Publication No. 77, 1907, p. 508.

since they were obtained by the subject himself and of necessity only during the waking hours. The relationship between the average pulse-rate for the day and the metabolism was so striking it seemed desirable to make further experiments to study the relationship between the pulse-rate and the metabolism.

In order to avoid the errors incidental to the taking of the pulse-rate by the subject himself we used a pneumograph, which was placed around the chest of the subject and the pulse was counted from the minor vibrations of the pointer. In many experiments this method was very successful, in others the results were not so satisfactory, as frequently, particularly during sleep, the subject would unconsciously move into such a position that the pneumograph would not properly register. In a number of experiments a sufficiently accurate count was made to enable us to present the results together with the corresponding metabolism. The values have been collected in table 105.

It is seen that the pulse-rate increases during the waking hours of the day as compared with the night. The results show conclusively that the pulse-rate is a general index of the metabolism, and indeed, we can obtain an approximate idea of the total metabolism from the pulse-rate of a subject, although the rate per minute of itself is not necessarily a general index of the katabolism for all individuals. One subject may have a high pulse-rate per minute with a lower general katabolism than another who has a much lower pulse-rate. It was seen early in the experimenting that the numerical value of the pulse-rate had no relation whatever to the absolute values for metabolism, but relatively speaking, on the same individual with a low pulse-rate there would be a lower metabolism than with a higher pulse-rate. The results of the investigation here reported are only tentative, and it is hoped by means of a stethoscope, which is more accurate than a pneumograph, to obtain values which may serve for better comparisons in subsequent experiments.

It is furthermore clear that while the pulse-rate may give a general index of the increased katabolism and of the internal muscular work, including muscular tonus, it is highly probable that the blood-pressure also plays an important rôle in the total katabolism and that one should know not only the pulse-rate but also the blood-pressure. It is not inconceivable that there may be some relationship established between the two factors, pulse-rate and blood-pressure, on the one hand, and metabolism on the other. It is with this in mind that special experiments are now in progress in the Nutrition Laboratory. The value of such observations for bedridden patients is obvious. It is not easy to determine the total energy output of a bedridden patient, but with a given body-weight and a given pulse-rate and blood-pressure, it may be possible to form an approximate idea of the total katabolism from these factors. At least it would appear that variations in the two factors may prove of value in judging of variations in the metabolism.

In considering the results given in table 105 it is necessary to bear in mind that there is no attempt to compare muscular activity in the different experiments, and the sole basis for comparison is the pulse-rate. As a matter of fact,

TABLE 105.—*Variation in pulse-rate, carbon-dioxide elimination, and heat production during waking hours (7 a. m. to 1 p. m.) as compared with results during sleep (1 a. m. to 7 a. m.).*

Subject and experiment number.	Date.	Average pulse-rate per minute.			
		(a) 1 a. m. to 7 a. m.	(b) 7 a. m. to 1 p. m.	(c) Increase. (b—a)	(d) Percentage increase. (c ÷ a)
A. H. M.:					*Per cent.*
Experiment No. 81	Nov. 22, 1905	42	57	15	35.7
H. C. K.:					
Experiments Nos. 154 and 155.	May 16 and 23, 1906	46.5	54	7.5	16.1
Experiments Nos. 82, 154, and 155	Nov. 24 and 25, 1905, and May 16 and 23, 1906	51	61	10	19.6
Experiment No. 82	Nov. 24 and 25, 1905	54.5	67	12.5	22.9
N. M. P.:					
Experiment No. 85	Dec. 10, 1905	62	70	8	12.9
H. R. D.:					
Experiment No. 151	May 18, 1906	57	69	12	21.1
Experiment No. 83	Dec. 6, 1905	68	85	17	25.0

Subject and experiment number.	Date.	Carbon dioxide eliminated per hour.			
		(e) 1 a. m. to 7 a. m.	(f) 7 a. m. to 1 p. m.	(g) Increase. (f—e)	(h) Percentage increase. (g ÷ e)
A. H. M.:		*Grams.*	*Grams.*	*Grams.*	*Per cent.*
Experiment No. 81	Nov. 22, 1905	19.3	26.8	7.5	38.9
H. C. K.:					
Experiments Nos. 154 and 155.	May 16 and 23, 1906	24.8	27.0	2.2	8.9
Experiments Nos. 82, 154, and 155	Nov. 24 and 25, 1905, and May 16 and 23, 1906	24.8	32.0	7.2	29.0
Experiment No. 82	Nov. 24 and 25, 1905	24.8	37.0	12.2	49.2
N. M. P.:					
Experiment No. 85	Dec. 10, 1905	24.3	33.5	9.2	37.9
H. R. D.:					
Experiment No. 151	May 18, 1906	21.6	24.4	2.8	13.0
Experiment No. 83	Dec. 6, 1905	21.7	28.2	6.5	30.0

Subject and experiment number.	Date.	Heat produced per hour.			
		(i) 1 a. m. to 7 a. m.	(j) 7 a. m. to 1 p. m.	(k) Increase. (j—i)	(l) Percentage increase. (k ÷ i)
A. H. M.:		*Cals.*	*Cals.*	*Cals.*	*Per cent.*
Experiment No. 81	Nov. 22, 1905	59.2	90.0	30.8	52.0
H. C. K.:					
Experiments Nos. 154 and 155.	May 16 and 23, 1906	76.2	84.0	7.8	10.2
Experiments Nos. 82, 154, and 155	Nov. 24 and 25, 1905, and May 16 and 23, 1906	74.9	98.3	23.4	31.2
Experiment No. 82	Nov. 24 and 25, 1905	73.6	112.6	39.0	53.0
N. M. P.:					
Experiment No. 85	Dec. 10, 1905	79.1	106.4	27.3	34.5
H. R. D.:					
Experiment No. 151	May 18, 1906	63.2	71.5	8.3	13.1
Experiment No. 83	Dec. 6, 1905	70.8	97.7	26.9	38.0

during the morning period from 7 a. m. to 1 p. m. the muscular activity would be greater than during the night period, but the important point here is that there was sufficient muscular activity to increase the pulse-rate during the forenoon by a certain percentage. Was or was not the metabolism increased by a similar or proportional percentage? It is only on the basis of variations in pulse-rate that the values expressed in table 105 are to be considered. In experiments with the same subject it is seen that the increase in metabolism is roughly proportional to the increase in pulse-rate.

METABOLISM DURING DIFFERENT ACTIVITIES REFERRED TO A COMMON STANDARD.

From the results of a large number of experiments on different individuals, an average figure for the metabolism in different states of bodily activity may be obtained. It is clear, however, from all the tests here reported that each individual is to a certain extent a law unto himself. With a given body-weight and height, the metabolism is approximately constant under conditions of like bodily activity. One of the greatest difficulties in attempting to estimate the metabolism of an individual during the day is not the determination of the body-weight, or the height, or the general personal impression of the physical characteristics of the individual, but the striking variations in muscular activity, particularly the minor muscular activity. If each person were subjected to a certain vigorous muscular test and required to perform a certain amount of external muscular work, such as riding a bicycle-ergometer, the total katabolism could be estimated with great accuracy. It is the minor muscular movements, muscular tonus, involuntary muscular movement, pulse-rate, respiration-rate, and blood-pressure that influence the total katabolism, each in a small way, but all in a cumulative degree that interferes seriously with any attempt to compute the exact katabolism.

By far the most satisfactory basis for comparing different individuals is during sleep, for as has been seen in all the comparisons heretofore made, the variations from the normal are smallest during the sleeping period. Even when the subjects are asleep, however, noticeable variations are found and these can probably be considered, in large part, as a true index of the variations in muscular activity with the different individuals during sleeping hours. Under the present conditions of experimenting, where the pneumograph is used simply to record the respiration rate and minor bodily movements, such a method of approximating the muscular activity in different experiments is readily obtained. This procedure was not, however, in vogue at the time these experiments were made and hence we have not a proper comparison.

PERCENTAGE VARIATIONS IN METABOLISM DURING DIFFERENT ACTIVITIES AS COMPARED WITH SITTING.

These experiments were all planned with a view to studying a large number of individuals, and the importance of duplicates with the same individual, or of so planning the experiments as to study certain definite points, was not

insisted upon in all cases. In recent investigations with more sensitive calorimeters which permit of experimental periods as short as one hour, it has been found that the human body gives wonderfully accurate results when used for experimenting. With the same muscular activity and the same preceding diet, the metabolism can be predicted with almost unerring accuracy. Until a large number of other experiments have been made in which the energy transformation and katabolism involved in the ordinary household routine of everyday life have been more completely studied, we can not compute the daily requirement of man on a very accurate basis, yet the experiments here reported enable us to form some general opinion of the variations in the energy transformations during the day.

Assuming the energy transformation when a man is sitting quietly at rest (the condition obtaining in the large majority of our experiments) in a chair as 100, we can compute the relative variations above or below this point with either decreased or increased muscular activity. Thus, during sleep the muscular activity is very much decreased, and the total katabolism is less. In standing, the katabolism is somewhat greater than in sitting. On this basis, the relative values for a number of the various muscular activities have been

TABLE 106.—*Percentage variations in the average output of carbon dioxide and heat and intake of oxygen under different conditions of activity as compared with sitting.*

[Sitting = 100.]

Muscular activity.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat produced.
	Per cent.	*Per cent.*	*Per cent.*
Man at rest, sleeping	70	79	78
Man at rest, awake, sitting up	100	100	100
Man at rest, standing	112	116	117
Man at very severe muscular exercise	746	786	673

computed and presented in table 106. It is very difficult to express what is meant by the various terms—light muscular work, moderate muscular work, severe muscular work, and very severe muscular work—and hence no attempt is made here to define them. The very severe muscular work is included simply to show the energy transformation when a man is working at nearly the limit of his strength and endurance. Unfortunately one of the most highly desired factors in ordinary life is missing in this case, namely, the energy transformation during walking. With a calorimeter that is now being designed and shortly to be built at the Nutrition Laboratory, the problem of the motion of forward progression and energy transformation attendant thereon will be given a special consideration. Until this apparatus is perfected and tested, the only information we have that is in any way satisfactory are the observations of Zuntz in which a portable gas-meter was used. These observations signify that there is an hourly expenditure of about 160 calories over and above the resting maintenance requirement by a man of 70 kilos walking along a level road at a

rate of 2.7 miles per hour. The results of the comparisons expressed in terms of the metabolism when sitting quietly are given in table 106.

While the figures presented in table 106 are rough approximations of the variations in metabolism due to changes in muscular activity, they must not be taken as indicative of the exact transformations measured on any given individual or on any uniform set of individuals, consequently the differences in the percentages in the three factors—carbon dioxide, oxygen, and heat—are not as significant as they would otherwise appear. The fact that during very severe muscular exercise there is an increase of 646 per cent in the carbon dioxide and but 573 per cent in the heat does not represent the true condition. As a matter of fact, as will be seen in the preceding discussion, the experiments during very severe muscular work were made on one subject, and variations in diet and storage of glycogen could not be taken into consideration in experiments of so short a duration. The values in this table are to be taken, therefore, as indicating only in a general way the differences of the different factors of metabolism under different conditions of muscular activity. The experiments were not designed to be made on constant diet and with absolutely constant muscular activity, and hence the true comparisons between the three factors can not properly be made. Of special significance is the fact that during severe, exhausting muscular work, almost at the limit of human endurance, the metabolism may be from 700 to 800 per cent of the resting metabolism when sitting. During sleep the metabolism falls to not far from 75 per cent of the value when at rest and sitting quietly.

VALUES FOR THE METABOLISM DURING DIFFERENT ACTIVITIES AS COMPARED WITH SITTING.

From the large number of experiments when the subject was at rest and sitting or sleeping, we have certain definitely established values for the carbon-dioxide exhalation, oxygen absorption, and heat production. From the percentages given in table 106 it is possible to compute the probable carbon-dioxide exhalation, oxygen absorption, and heat production of individuals standing and during very severe muscular exercise. These values have been computed and are given in table 107.

TABLE 107.—*Amounts of carbon dioxide eliminated, oxygen absorbed, and heat produced during various activities as calculated using the results "awake, sitting up" as standard.*

[Amounts per hour.]

Muscular activity.	Carbon dioxide eliminated.	Oxygen absorbed.	Heat produced.
	Grams.	*Grams.*	*Calories.*
Man at rest, sleeping [1]	23	21	71
Man at rest, awake, sitting up [2]	33	27	97
Man at rest, standing [2]	37	31	114
Man at very severe muscular exercise [2]	248	213	653

[1] Average body-weight 66.6 kilograms. [2] Average body-weight 64.5 kilograms.

As the result of experiments on 55 men, with an average body-weight of 64.5 kilograms, awake and sitting quietly in a chair, it was found that the average carbon-dioxide exhalation amounted to 33 grams per hour, the oxygen absorption 27 grams, and the heat production 97 calories. With 17 different men asleep with an average body-weight of 66.6 kilograms, the average carbon-dioxide exhalation was 23 grams, oxygen absorption 21 grams, and the heat production 71 calories. Using the factors for the percentage increase in the metabolism due to the muscular exercise of standing and for very severe muscular work, the values as given in table 107 show that during very severe muscular work the carbon-dioxide exhalation may amount to 248 grams per hour, the oxygen absorption to 213 grams and the heat production to 653 calories. As a matter of fact a series of experiments made with a professional athlete showed that as much as 625 calories were actually measured.

In an earlier publication[1] it was pointed out that if values were known for the approximate metabolism of varying conditions of muscular activity, one could compute with reasonable accuracy the total metabolism for the day, and in this earlier publication attempts were made to designate the various kinds of muscular work as light, moderate, severe, and very severe. The futility of thus attempting to indicate a degree of muscular activity by these adjectives has been seen and no attempt will here be made to do this. We believe that the results presented in table 107 for the metabolism during standing are reasonably accurate and can be used in such computations, and we believe, furthermore, that the metabolism during very severe muscular work indicates the metabolism under conditions where the work was almost to the limit of human endurance and strength. These two points are reasonably well fixed. It is to be hoped that subsequent experiments will supply the missing data with special reference to the energy requirement during walking. Until these factors have been determined it will be practically impossible to compute the total energy transformation of man during ordinary daily activity.

On the other hand, the values here given for sleep and for sitting in a chair will be of some service, it is hoped, in calculating the energy transformation of convalescents and of bedridden patients. At present too little knowledge is available with regard to the metabolism during recovery from a severe drain upon body-material to predict accurately the metabolism. Thus it was found that the recovery following a fast[2] resulted in a very noticeable storage of body-material, nitrogen, and fat, although the question is as yet unsettled as to whether the nitrogenous material stored under such conditions becomes active protoplasmic tissue with the highest degree of metabolic activity. The question can only be solved by an extensive series of experiments in which the nature of the stored material can be studied from many standpoints.

[1] Atwater and Benedict, U. S. Dept. Agr., Yearbook 1904, p. 205.
[2] Benedict, Carnegie Institution of Washington Publication No. 77, 1907.

The results presented in this report are to be considered simply as indicating the normal metabolism of healthy young men at rest and under several conditions of muscular activity. The variations from the normal exhibited by the individual can be seen by an examination of the tables. The attempt is made to point out the cause of the variations in so far as possible, but with so complex a process as the energy transformation and katabolism in the body, it is clearly futile to attempt to predict with great accuracy either the katabolism or the energy transformations of a given individual. Approximate values that may prove of practical use can be obtained by means of some of the factors outlined in this report. With more accurate and improved calorimeters, there should be in the course of a few years the addition of many factors, at present entirely unknown.